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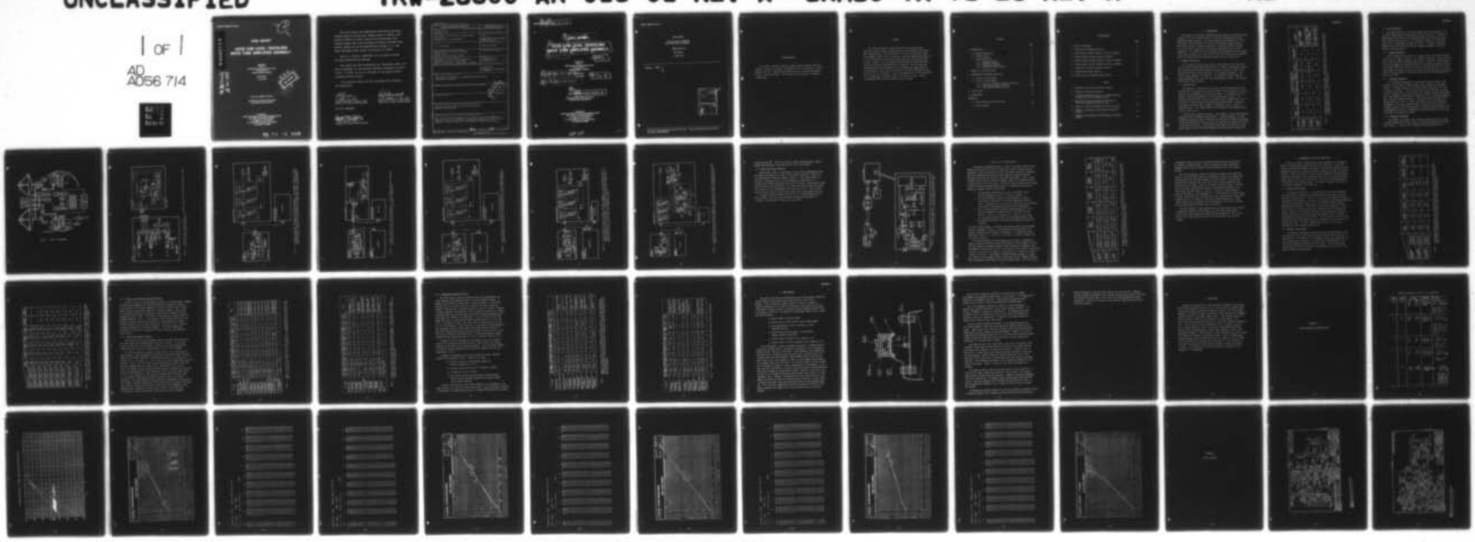

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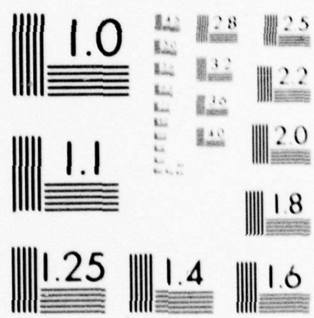
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FINAL REPORT

9438 LOW LEVEL TRAVELING WAVE TUBE AMPLIFIER ANOMALY

Prepared by
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TRW Defense and Space Systems Group
One Space Park
Redondo Beach, CA 90278

REVISION A

7 June 1978

Report No. 28600-AR-016-01

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Prepared for
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Los Angeles, CA 90009

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Capt G. D. Nordley, SAMSO/SKT, was the Project Officer for Space Communications Systems.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of an investigation into an orbit failure of a LLTWTA on a DSCS-II satellite are presented. The possible causes of this failure are examined in light of orbit data and laboratory simulation testing.

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PREFACE

This report presents the 9438 Low-Level Traveling Wave Tube Amplifier (LLTWTA) anomaly investigation with the resulting conclusions and recommendations. The 9438 satellite is still in operation, using the redundant LLTWTA, and is providing all desired communications service. It was not possible to state definitively the exact cause of the 9438 failure. Rather, a set of candidate failure modes was identified which could have caused the observed failure signature. Each of these was examined during the investigation, and a judgment was made concerning the likelihood of such a failure occurring in LLTWTAs scheduled for use on future DSCS II satellites. It was concluded that all of the identified failure modes were isolated in nature, not likely to recur. Hence, no recommendations are made concerning future LLTWTAs.

CONTENTS

ILLUSTRATIONS

TABLES

1. INTRODUCTION

A failure of a low-level traveling wave tube amplifier (LLTWTA) occurred in August 1977 on 777 Satellite 9438. A detailed investigation of this anomaly has been conducted. This investigation included analysis of telemetry data, failure simulation testing on a breadboard LLTWTA, review of past failure history, review of application, derating, and part testing of critical parts, review of the TWT heater configuration and critical dimensions. The results of this investigation are summarized in this report, along with conclusions as to the nature of the orbit failure and recommendations for future activities regarding LLTWTAs on the 777 satellites.

1.1 ANOMALY DESCRIPTION

On 28 August, at approximately 0700Z, DCA notified the STC that 9438 narrow coverage communications had been lost at 0650Z. An emergency support was scheduled. When telemetry became available (at 0723Z), it was noted that the NCLLTWTA-2 had low readings on all telemetry parameters. That amplifier was commanded OFF, then ON. All parameters had the same low values, whereupon the -1 amplifier was commanded ON at 0806Z. DCA reported communications were restored.

1.2 TELEMETRY DATA

No telemetry is available for the time at which the anomaly occurred. The data that is available for the failed TWTA - the last pass prior to the anomaly and the emergency pass after the anomaly - is summarized in Table 1. The data indicates decreases in all TWTA voltages and currents. The cathode current and helix current are probably zero, although the values in the table are those derived from telemetry calibration data. Obviously, the negative value for helix current is impossible, and it should be considered zero. It has been generally concluded that the cathode current really is zero, also.

The data does establish one fact: this anomaly is quite different from those previously encountered with HLTWTAs. In those anomalies, all TWTA parameters read zero counts, indicating the TWTA was off either by operation of an overcurrent trip circuit or due to a blown fuse (or possibly a failure of the turn-on circuit). In the case of the LLTWTA, at least part of the power supply circuits are receiving power and functioning to some extent.

TIME/DATE	TELEMETERED PARAMETERS						REMARKS
	INPUT CURRENT(MA)	CATHODE CURRENT(MA)	HELIX CURRENT(MA)	FILAMENT VOLTAGE(V)	HELIX VOLTAGE(V)	TEMPERATURE (°F)	
28 AUGUST 0315-0330Z	193	5.35	0.046	3.913-3.977	1715-1741	90	LAST PASS PRIOR TO ANOMALY. NOMINAL DATA.
28 AUGUST 0723-0804Z	72-82	0.165*	-0.027*	3.012-3.198	1646-1690	83	FIRST DATA AVAILABLE AFTER ANOMALY. ENDS WITH OFF COMMAND.
28 AUGUST 0805Z	77	0.165*	-0.027*	3.033	1658	83	DATA WHEN NCLLTWTA-2 WAS TURNED ON AGAIN.

Table 1. NCLLTWTA-2 Data, Before and After Anomaly.* (The values for helix and cathode current are, in fact, taken to be zero. The non-zero values shown are due to bias and offset in the telemetry conditioning circuits in the TWTA.)

1.3 SYSTEM INTERFACES

The LLTWTA functions as the driver amplifier for the HLTWTAs in the EC and NC communications transmitters on the 777 satellite. An identical backup unit is provided for each operating amplifier, making a total of four LLTWTAs on each satellite. The functional location of the LLTWTAs within the 777 transponder is shown in Figure 1. The major interfaces between the satellite and the TWTAs are command, telemetry, structural, thermal, and primary power.

1.3.1 Command Interface

The ON command for the LLTWTA is a steady state +5 VDC signal supplied by the SLA. As shown in Figure 2, this signal is supplied from the 5 VDC output of the SLA converter through relay contacts in the SLA. Signal return for this ON command is through the TWTA, SLA, and despun platform structure. It should be noted that the only circuitry in the SLA peculiar to an individual TWTA are the two printed circuit board traces and one wire connecting that TWTA to the common +5 VDC source used to provide the ON command voltage for all TWTAs.

1.3.2 Telemetry Interface

Five telemetry measurements are available from each LLTWTA; input current, helix voltage, filament voltage, helix current, and cathode current. Interface schematics for each of these measurements are shown in Figures 3 through 7. It should be noted at this point that the helix current, cathode current, helix voltage and filament voltage measurements are cross-strapped in the satellite harness with the corresponding measurement from the redundant amplifier. Since only one of each pair of redundant amplifiers is on at a time, the effect of this cross-strapping arrangement is to place a parallel passive resistive load across the telemetry output of the operating tube. The effect of this parallel load on measurement accuracy is accounted for when the telemetry circuits are calibrated by the amplifier vendor.

1.3.3 Mechanical Interface

The LLTWTAs are mounted to the satellite platform with four screws inserted through feet at the corners of the amplifier chassis into platform inserts. A layer of RTV is applied to the platform prior to

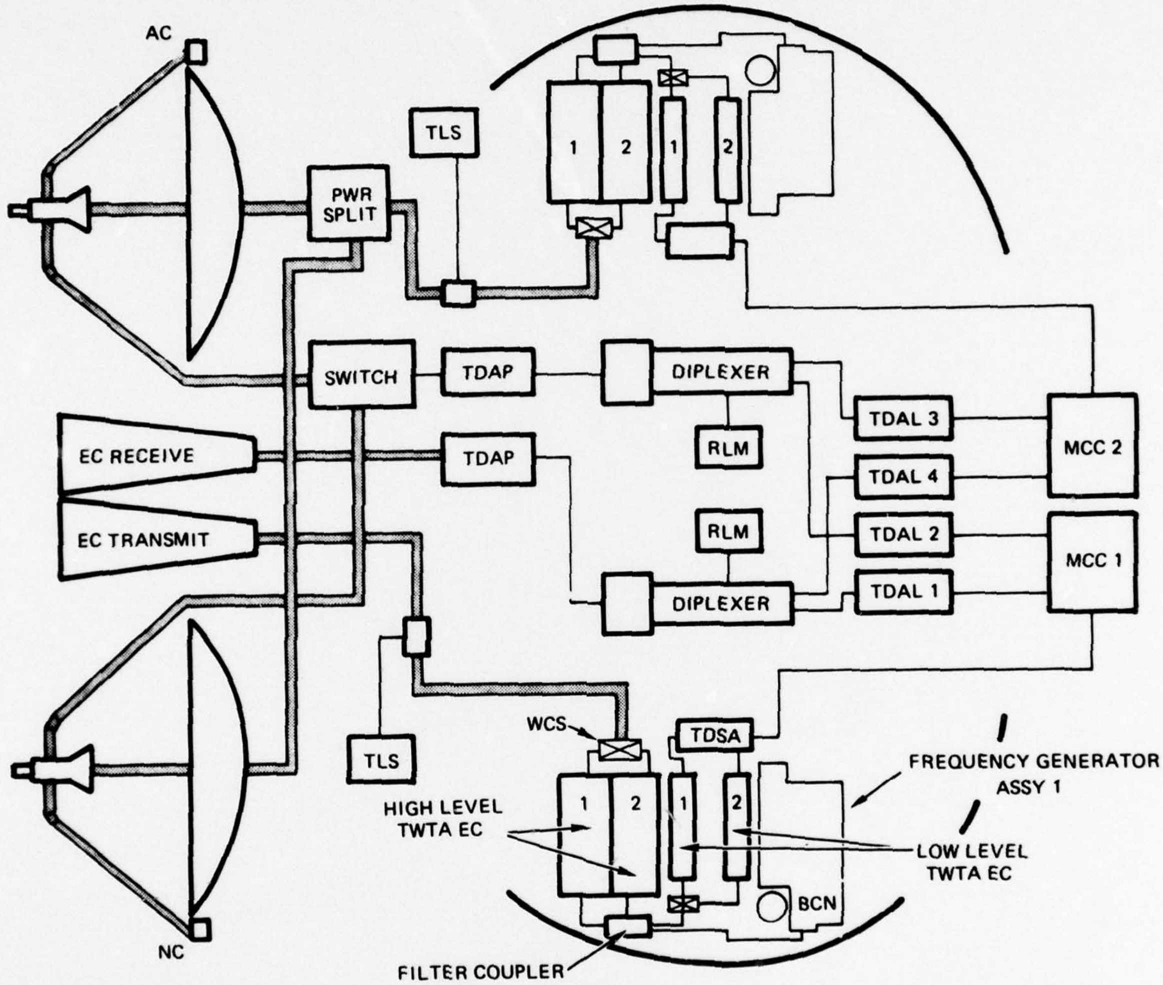


Figure 1. DSCS II Transponder

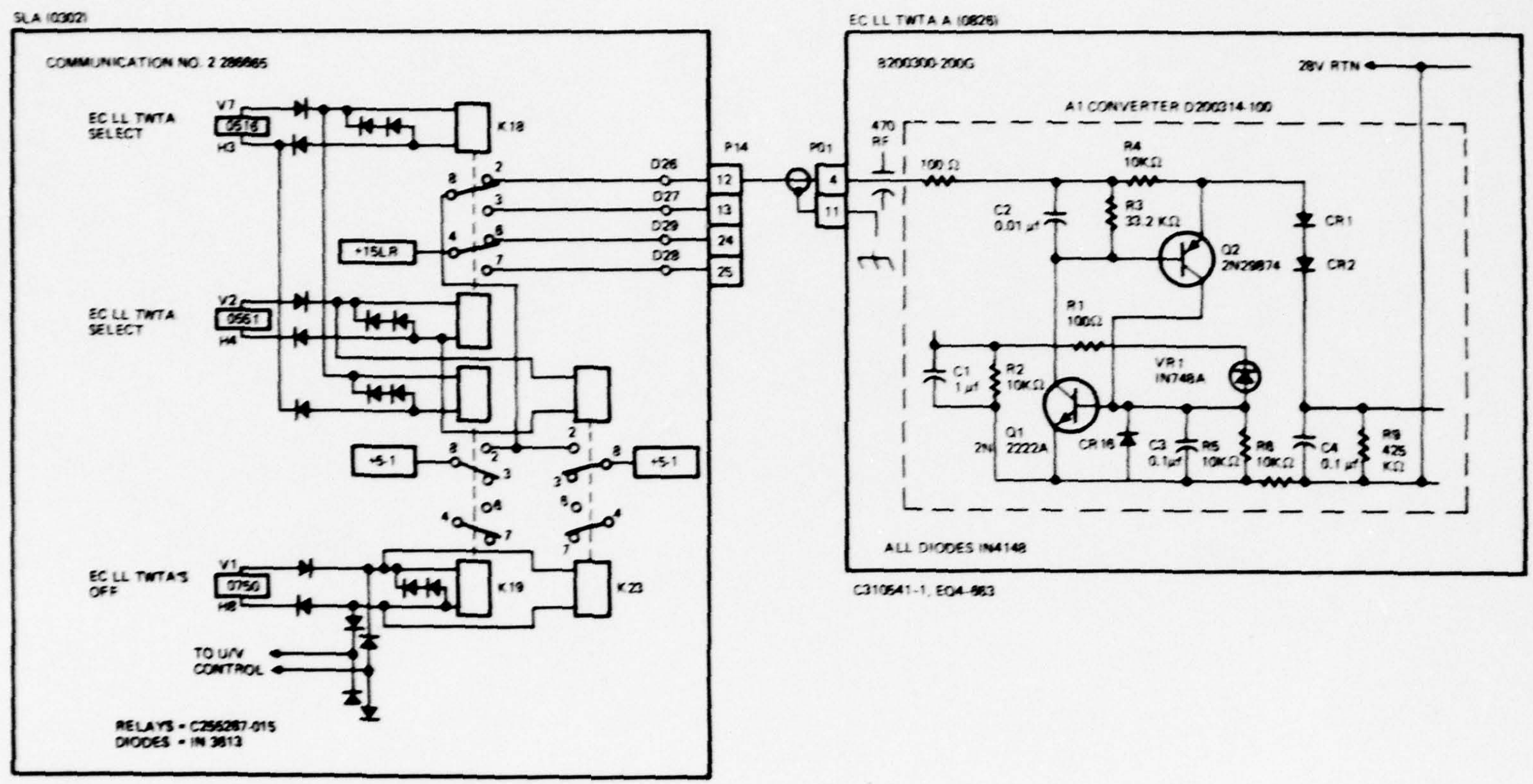


Figure 2. LLTWTA Turn-On Command Interface. (A steady state 5 VDC signal from the SLA is used to turn on each LLTWTA individually.)

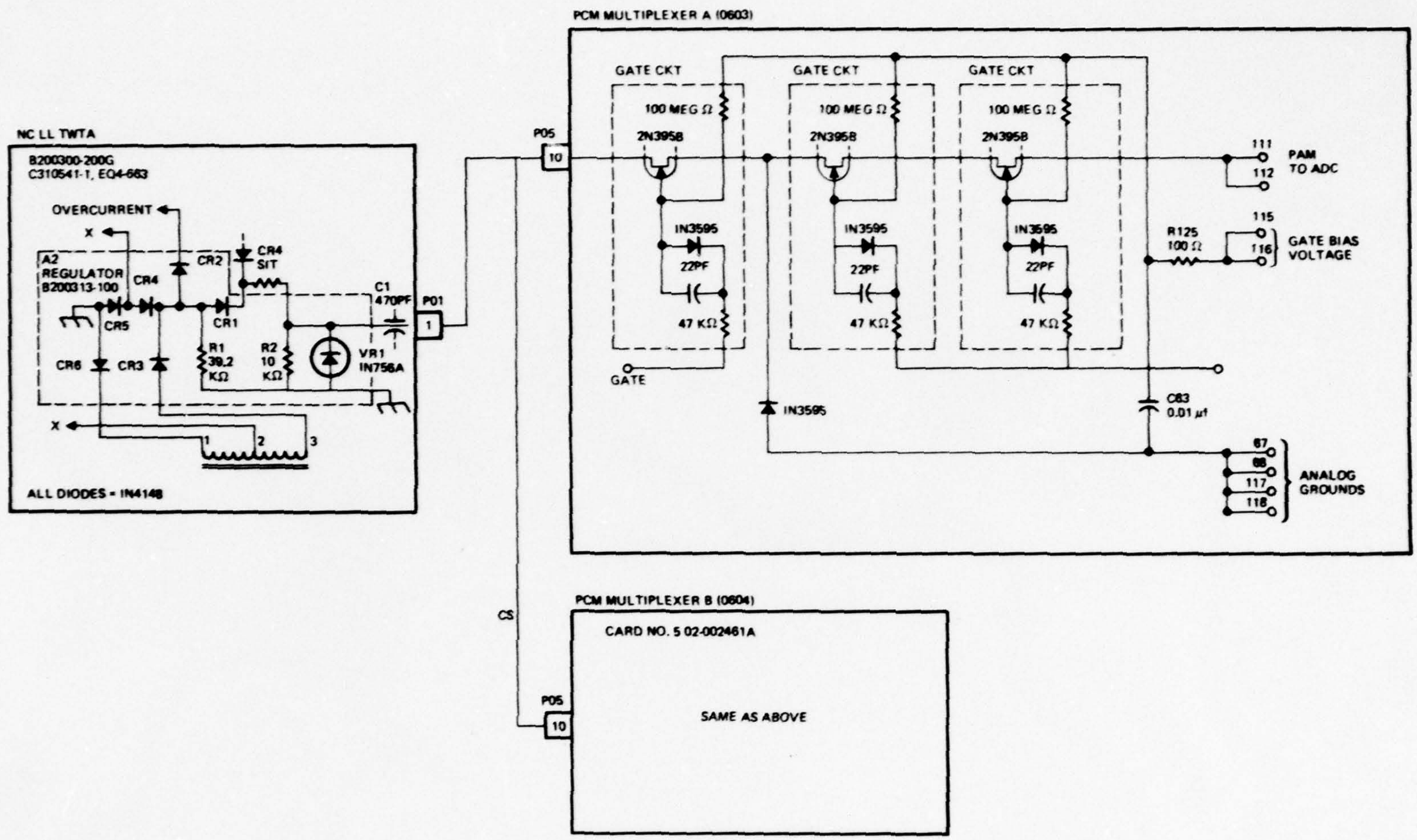


Figure 3. LLTWTA Input Current Telemetry Interface Schematic. (A saturable reactor is used to measure TWTA input current and generate an overcurrent signal. The overcurrent signal is used to trigger a trip circuit (not shown) which shuts down the TWTA.)

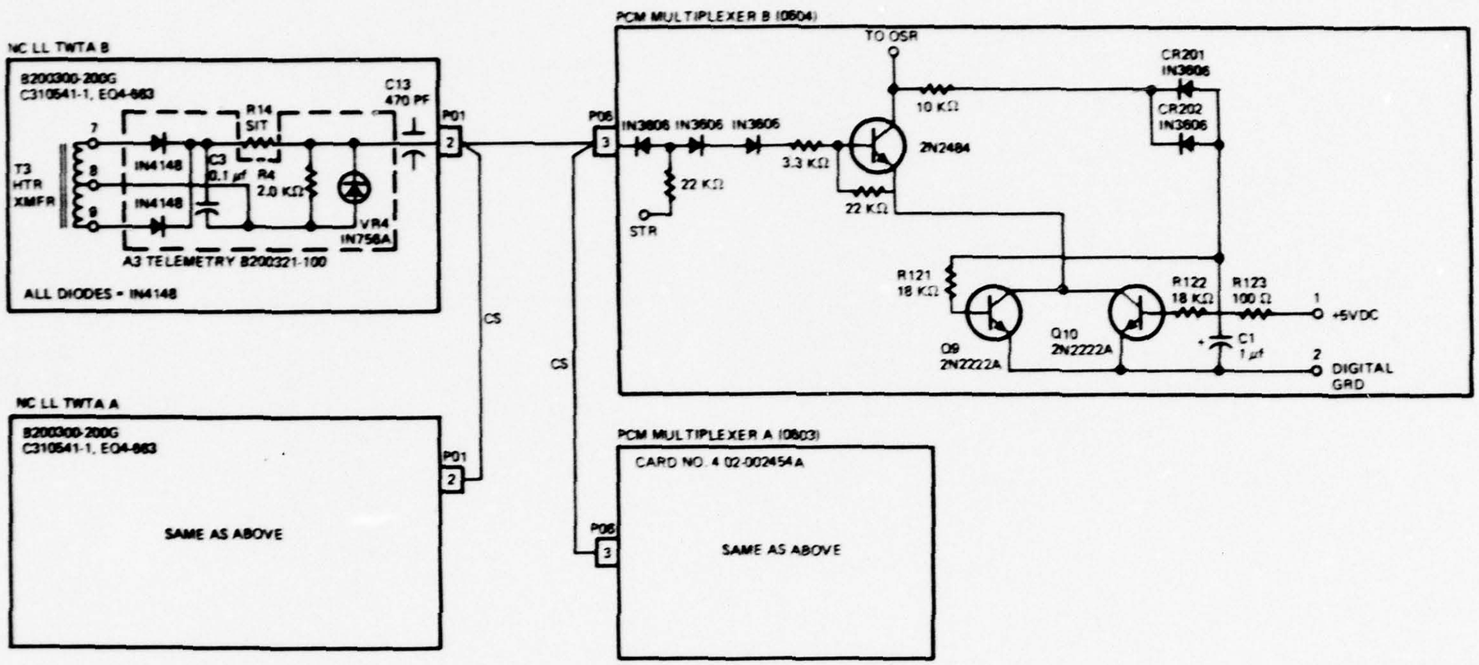


Figure 4. LLTWTA Filament Voltage Interface Schematic. (The filament voltage is measured indirectly using an auxiliary winding on the heater transformer.)

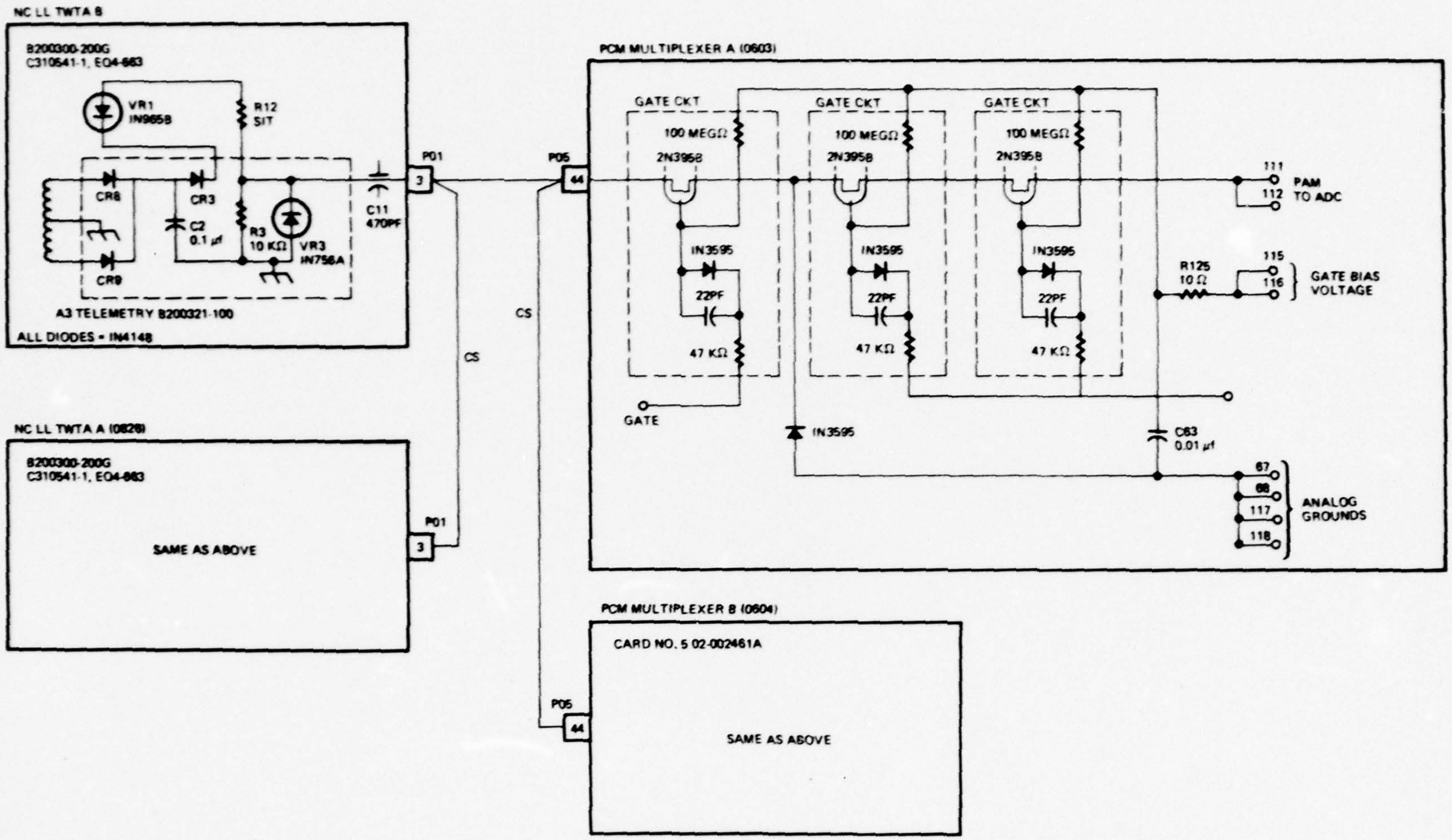


Figure 5. LLTWTA Cathode Voltage Telemetry Interface Schematic. (The cathode voltage is measured indirectly using an auxiliary winding on the high voltage transformer.)

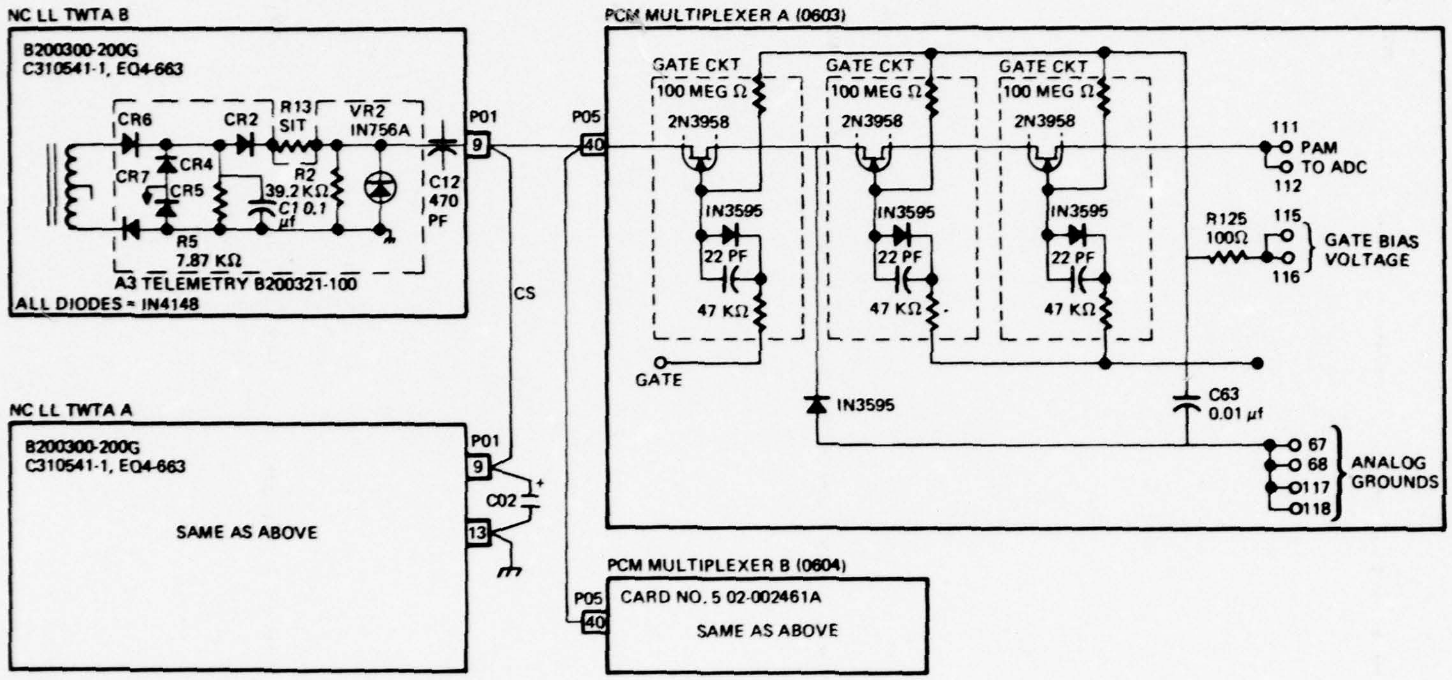


Figure 6. LLTWTA Cathode Current Telemetry Interface Schematic. (The cathode current is measured using a saturable reactor in the cathode voltage output section of the high voltage module. A capacitor is installed in the harness to reduce the magnitude of noise spikes on the TWTA telemetry output.)

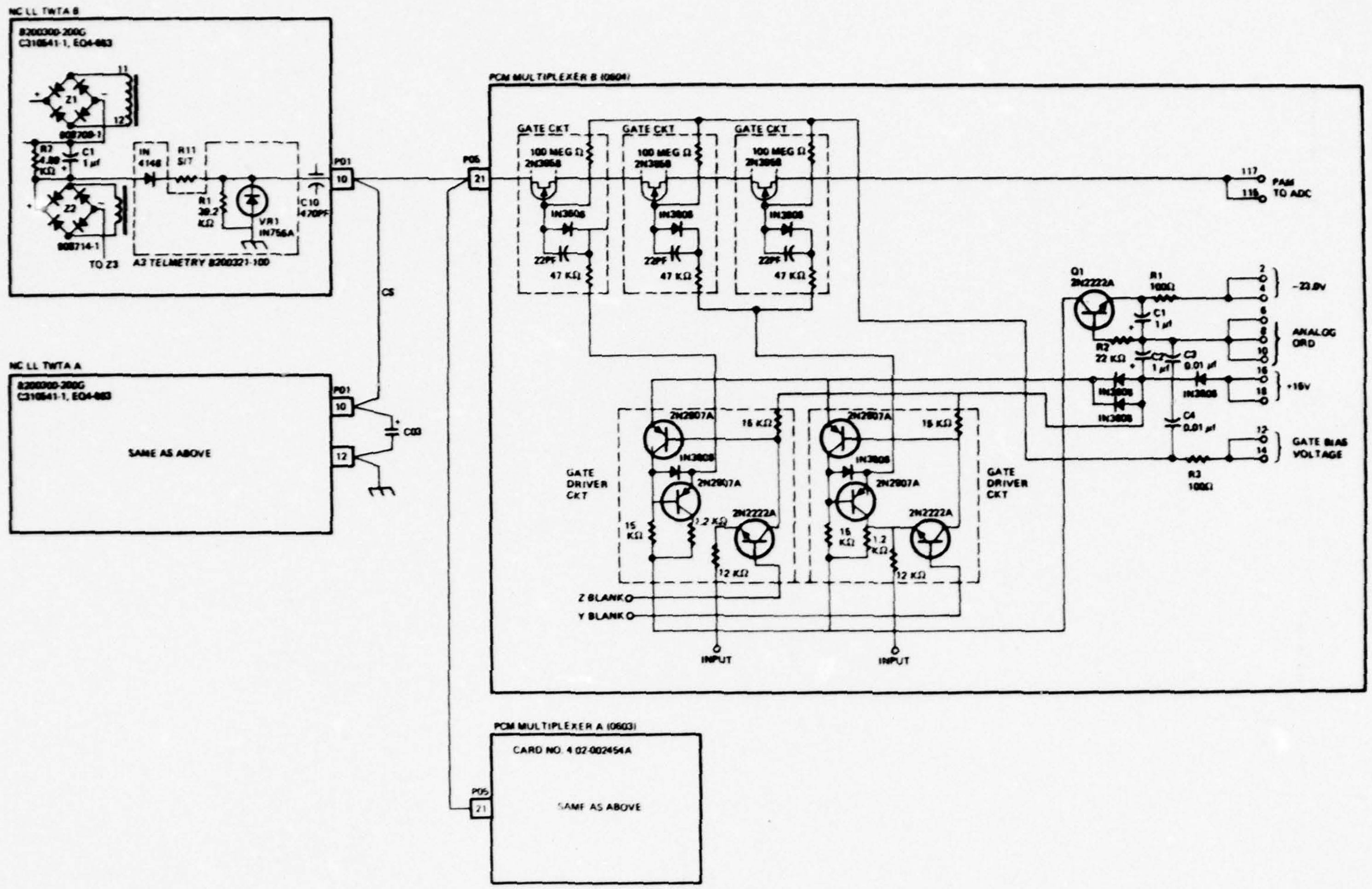


Figure 7. LLTWTA Helix Current Interface Schematic. (The helix current is measured as a voltage across a series resistor in the helix voltage section of the high voltage module.)

installing the TWTA. The RTV is used to insure intimate thermal contact between the baseplate of the TWTA and the satellite platform.

1.3.4 Electrical Power Interface

Fused primary power is distributed to each LLTWTA independently from the Power Distribution Unit (PDU) on the spinning platform. Details of this distribution scheme are shown in Figure 8. The primary power from the PCU is regulated at 32.4 $\pm$0.2 VDC whenever the satellite is in sunlight not recharging the batteries after an eclipse. During each eclipse and for several hours thereafter, the primary bus goes through one voltage cycle from 32.4 V to approximately 26 V and back to 32 V. This voltage cycle occurs 45 times in one eclipse season, two eclipse seasons per year.

The nominal primary current load at 32.4 V is approximately 190 ma for a LLTWTA. The slip rings are rated for continuous operation at 3 A each. Two are used in parallel for each TWTA.

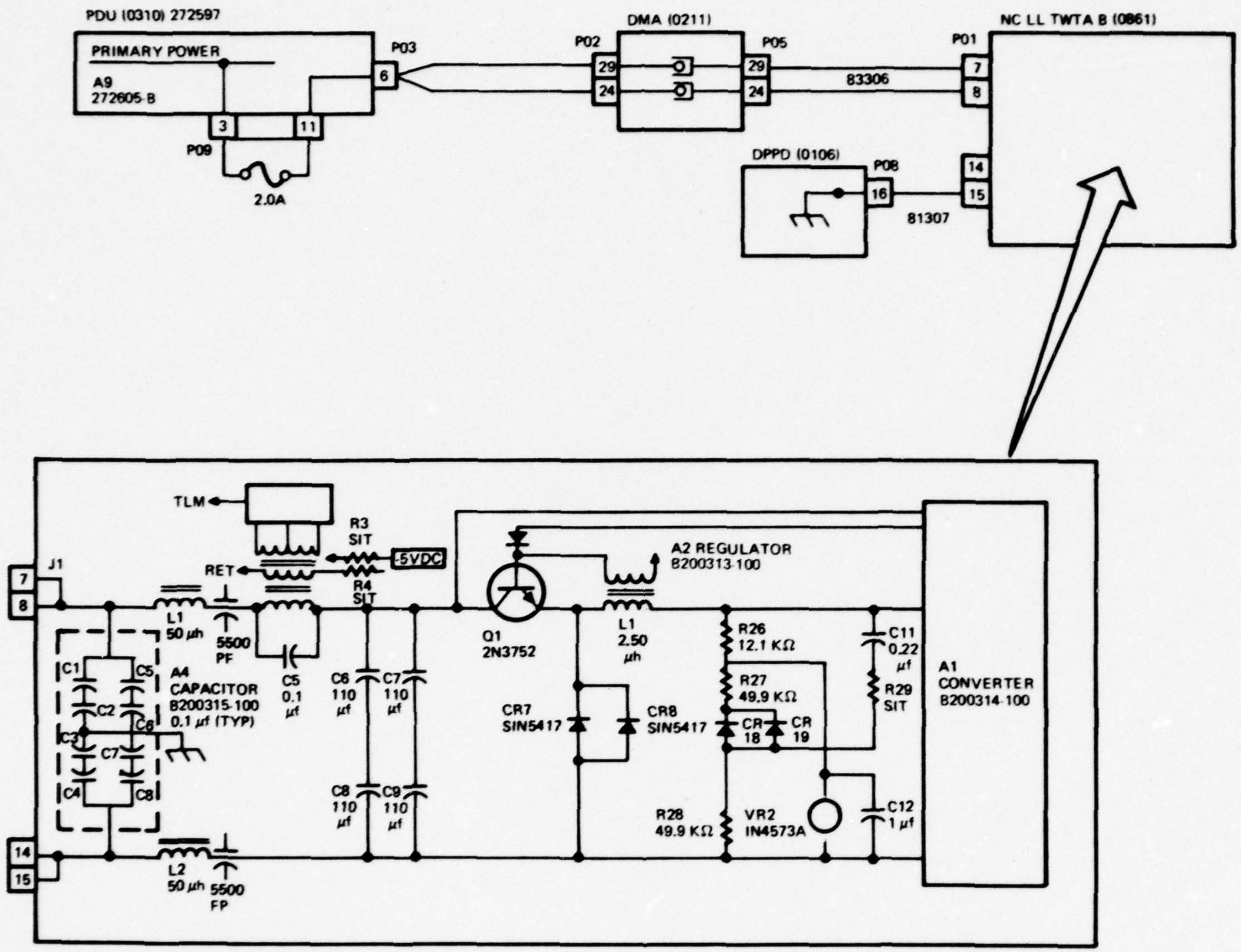


Figure 8. LLTWTA Primary Power Interface. (Primary power is supplied to each individual LLTWTA through a 2 A fuse and two parallel slip rings.)

2. ANALYSIS OF TELEMETRY DATA

The amplifier parameters given in Table 1 are direct copies of the numerical values derived from the calibration curves in use at the SCF. Calibration curves are derived from ones used during satellite integration which are themselves derived from vendor supplied calibration curves developed during factory testing of the TWTA power supply. Also, it must be kept in mind that the satellite telemetry system is a digital one with a quantization of 20 mV per count. The factors which can obscure the actual value of the measured TWTA parameter when it is deduced from satellite telemetry voltages include the following:

1. The telemetry conditioning circuits in the TWTA's have a slightly temperature sensitive transfer function.
2. Only one calibration curve for each parameter is used in the satellite calibration file during Integration and Test (I&T). This curve is an average one drawn approximately through the center of the temperature spread for each parameter.
3. Only a limited amount of computer storage capacity is available for telemetry calibrations both in the I&T file and the SCF. Hence, some compromises are required in matching the stored calibration curves to the measured vendor curves.
4. The quantizing factor of the satellite telemetry system is 20 mV/count.

In light of these factors a telemetry uncertainty analysis was performed which is presented in Table 2. The detailed calibration curves, and computer equivalents are contained in Appendix A. An additional entry included in Table 2 is a listing of the change in telemetry voltages and associated parameters.

An initial analysis of the telemetry data in Table 2 indicated the heater voltage on the TWT had fallen sufficiently to stop cathode emissions The small amount of apparent cathode current indicated by telemetry after the anomaly is due to the fact that the cathode current telemetry conditioning circuit in the TWT has an output of approximately 2.0 V when the cathode current is in fact 0. The change in cathode voltage telemetry is caused by a change in the telemetry signal conditioning circuit transfer function when the cathode current goes to zero or slightly above. This circuit uses

		INPUT CURRENT	FILAMENT VOLTAGE	CATHODE VOLTAGE	CATHODE CURRENT	HELIX CURRENT
S/N 24-19 Nominal	Telemetry Voltage	2.54 to 2.58v	4.18 to 4.22v	2.26 to 2.46v	3.58 to 3.62v	0.42 to 0.46v
	Parameter Value	180 to 188 ma	3.88 to 3.92v	-1711 to -1745v	5.3 to 5.45ma	0.04 to 0.06ma
S/N 24-19 Anomaly	Telemetry Voltage	2.06 to 2.14v	2.90 to 3.12v	1.82 to 1.14v	1.98 to 2.02v	0.16 to 0.20v
	Parameter Value	30 to 110 ma	3.0 to 3.22v	-1643 to -1699v	0.1 to 0.15ma	0 ma
Δ from Normal	Telemetry Voltage	-.48 to -.44v	-1.28 to -1.10v	-.44 to -.32v	-1.60v	-.026v
	Parameter Value	-158 to -70ma	-.92 to -.66v	+102 to +16v	-5.35 to -5.15ma	-.04 to -.06ma

Table 2. Telemetry Uncertainty Analysis. (For a given telemetry voltage, an analysis was performed of the maximum and minimum parameter value which could exist. Significant variations can be seen in input current and filament voltage.)

a saturated reactor to sense the cathode voltage which is also sensitive to changes in cathode current. Hence, the apparent slight reduction in cathode current after the anomaly can be explained by the loss of beam current.

Due to the redundant current measurements included in the satellite system, it was possible to obtain an independent check that an anomaly had occurred within the TWTA which reduced its input current. The main bus current monitor measures the total satellite load being supplied by the Power Control Unit (PCU), exclusive of battery charging current. The data from this monitor confirmed that the bus load had been reduced by 70 to 120 ma after the TWTA anomaly. Further, it showed a similar decrease when the NCLLTWTA No. 2 was commanded off. The uncertainty in these changes is due to the quantizing of the main bus current monitor which is 60 ma per telemetry count. This data did confirm the apparent reduction in TWTA input current after the anomaly and the approximate value of the residual current being drawn by the TWTA after the anomaly.

The main emphasis of the subsequent failure investigation was directed at identifying specific failure modes in the TWT power supply heater circuit which could produce the observed failure signature. This circuit consists of a linear regulator and a DC to AC converter, plus the TWT filament.

3. BREADBOARD TESTING AND SIMULATION

A series of failure simulation tests were performed on a breadboard model of the TWTA power supply operating with a TWT load. During the course of these tests attempts were made to recreate the telemetry voltage signature of the orbit failure by simulating various external and internal failures. Opens and shorts of various active components within the power supply were simulated. Also certain partial short circuit (overload) and partial open circuit (series resistance) faults were simulated both within and external to the power supply. A schematic diagram of the LLTWTA is included in Appendix B for reference.

3.1 EXTERNAL FAILURE MODES

As discussed in Section 1.3, the LLTWTA has two primary interfaces with the satellite electrical system whose malfunction could cause misoperation of the amplifier. The first of these is the command interface; the second, primary power. The tests on the command interface were performed by reducing the command voltage from 5 V to the point where anomalous performance was observed. The results of this test are given in Table 3. As can be seen, it was not possible to reproduce the orbit anomaly signature. The tests on the power interface were performed by inserting a series resistance in series with the primary power source to the TWTA and gradually increasing the resistance. This was done to simulate a possible slip-ring failure where the series resistance of the slip ring increases with time. This test, summarized in Table 4, also did not reproduce the orbit anomaly characteristic.

3.2 INTERNAL FAILURE MODES

The internal failure mode testing was done in several phases, using data from the initial tests to indicate more refined follow-up tests to be performed. This report will not attempt to trace this chronology but will discuss the test results on a functionally allocated basis. The tests were primarily concerned with three areas: TWT and associated wiring faults, failures of the high voltage module, and failures of the heater voltage linear regulator.

		INPUT CURRENT	FILAMENT VOLTAGE	CATHODE VOLTAGE	CATHODE CURRENT	HELIX CURRENT	SWITCHING REGULATOR	LINEAR REGULATOR
BREADBOARD NOMINAL	TELEMETRY	1.66	3.91	2.23	3.62	0.82		
	PARAMETER	188ma	3.90v	-1730v	5.3ma	.186ma	1869v	17.37v
LOW COMMAND VOLTAGE (1.15v)	TELEMETRY	3.60	3.91	2.22	3.50	0.849		
	PARAMETER	280ma	3.93v	-1730v	5.4ma	0.18ma		
LOW COMMAND VOLTAGE (1.1v)	TELEMETRY	7.82	3.92	3.84	4.33	3.43		
	PARAMETER	430ma	3.94	-1996	6.0ma	0.83ma		

Table 3. Performance Characteristics of a LLTWTA Subjected to Application of Low Command Voltage. (The command voltage threshold for nominal LLTWTA power supply operation is slightly above 1.15 V. Below this value, the TWTA draws excessive input current.)

		INPUT CURRENT	FILAMENT VOLTAGE	CATHODE VOLTAGE	CATHODE CURRENT	HELIX CURRENT	SWITCHING REGULATOR	LINEAR REGULATOR
BREADBOARD	TELEMETRY VOLTAGE	1.66v	3.91v	2.23v	3.62v	0.82		
NOMINAL	PARAMETER VALUE	188ma	3.90v	-1730v	5.3ma	.186ma		
27Ω SERIES RESISTANCE (22.3v)	TELEMETRY VOLTAGE	3.65v	3.91v	2.22v	3.51v	0.790		
	PARAMETER VALUE	350ma	3.9v	-1730v	5.3ma	0.180ma		
29Ω SERIES RESISTANCE (21.6v)	TELEMETRY VOLTAGE	3.78v	3.91v	2.22v	3.51v	.798v		
	PARAMETER VALUE	360ma	3.9v	-1730v	5.3v	.180ma	-1263v	+254v
34Ω SERIES RESISTANCE (18.7v)	TELEMETRY VOLTAGE	4.24v	3.92v	2.21v	3.51v	.803v		
	PARAMETER VALUE	390ma	3.9v	-1723v	5.3ma	.18ma	-1259v	+254v
40Ω SERIES RESISTANCE (17.4v)	TELEMETRY VOLTAGE	3.52v	3.79v	1.42v	3.18v	.890v		
	PARAMETER VALUE	360ma	3.6v	-1598v	4.65ma	.21ma	-1165v	+235v
45Ω SERIES RESISTANCE (16.65v)	TELEMETRY VOLTAGE	3.05v	3.61v	1.08v	3.01v	.673v		
	PARAMETER VALUE	340ma	3.2v	-1539v	4.34ma	.158ma	-1124v	+224v
50Ω SERIES RESISTANCE (15.94v)	TELEMETRY VOLTAGE	2.75v	3.44v	.762v	2.84v	.495v		
	PARAMETER VALUE	320ma	3.0v	-1482v	4.05ma	.11ma +Climbing	-1085v	-214v
55Ω SERIES RESISTANCE (15.3v)	TELEMETRY VOLTAGE	2.52v	3.28v	.449v	2.67v	.430v		
	PARAMETER VALUE	300 ma	3.0v	-1426v +Dropping	3.7ma	.10ma +Climbing	-1045v	+206v
60Ω SERIES RESISTANCE (14.7v)	TELEMETRY VOLTAGE	2.31v	3.14v	.017v	2.34v	1.00v		
	PARAMETER VALUE	285ma	3.0v	-1349v	.26ma	.27ma +Dropping	-982v	+197v

Table 4. Operation of LLTWTA with Series Resistance in the Primary Power Distribution Lines. (With a series resistance greater than approximately 25 Ω, the LLTWTA power supply input current increases, while the filament voltage is relatively unchanged.)

3.2.1 Faults in the TWT and Associated Wiring

A series of tests of various opens and shorts of the TWT heater, cathode, and helix were conducted, the results of which are presented in Table 5. As can be seen from the data summarized in Table 5, none of these failure modes appeared to match the signature of the orbit anomaly. One or more of the resultant telemetry readings was significantly different from the corresponding orbit value. The closest failure mode was a heater short of somewhere between 5 and 7 Ω. The change in input current was close to the minimum value indicated by orbit telemetry, and the change in filament voltage telemetry close to the maximum value. Because of this, a specific review was performed of the heater geometry. The review, summarized elsewhere in this report, concluded this type of partial short appeared very unlikely.

3.2.2 High Voltage Module Failures

The results of the tests performed simulating various failure modes in the power supply high voltage module are given in Table 6. As with the results of the fault tests reported in Table 5, no failure mechanism was tested that gave a very close approximation to the F8 orbit anomaly.

Two failure modes were, however, tantalizingly close to matching the orbit anomaly. These two modes occur when one of the high voltage rectifier diodes in the heater converter is replaced with a small (3 Ω) resistor or is shunted by a 3 Ω resistor; i.e., CR1 or CR2 in the high voltage module partially shorted. In this case, the input current drops almost as much as indicated by orbit telemetry (67 ma in test versus a minimum of 70 ma in orbit). Also, the filament voltage telemetry becomes grossly inaccurate (an indicated value of approximately 2 V from calibration curves, versus an actual value of .38 to .46 V measured). This is due to distortions of the wave shape of the filament voltage when one output rectifier diode is no longer rectifying. This wave shape distortion depends on the degree of saturation of the filament voltage transformer with CR1 or CR2 partially shorted, and would vary greatly from unit to unit and as a function of the impedance of the shorted diode. Therefore, a partial short of CR2 or CR1 in the high voltage module cannot be ruled out as the cause of the orbit anomaly.

FAILURE MODE	INPUT CURRENT		FILAMENT VOLTAGE		CATHODE VOLTAGE		CATHODE CURRENT		HELIX CURRENT		SWITCHING REG. VOLTAGE	LINEAR REG. VOLTAGE	REMARKS
	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE			
BREADBOARD NOMINAL	1.66	188 ma	3.91	3.90 v	2.23	-1730 v	3.62	5.3 ma	0.82	.186 ma	18.69 v	17.37 v	
HEATER ON, E_K DISCONNECTED Δ FROM NOMINAL	1.28	108 ma	3.72 -.19	3.65 v -.25v	1.76	-1727 v	1.90	0 ma	.18	0 ma	16.87 v	16.4 v	HEATER VOLTAGE TOO HIGH
HV ON, FILAMENT DISCONNECTED Δ FROM NOMINAL	1.20	74 ma	5.63 +1.72	8.26 v +4.36 v	1.78	-1728 v	1.91	0 ma	.18	0 ma	16.83 v	16.76 v	HEATER VOLTAGE TOO HIGH
HV & FILAMENT DISCONNECTED	1.21	75 ma	5.63	8.3 v	1.79	-1729 v	1.91	0 ma	.18	0 ma	16.83 v	16.77 v	HEATER VOLTAGE TOO HIGH
HEATER SHORTED 0 Ω Δ FROM NOMINAL	1.38 -.28	128 ma -60 ma	2.44 -1.47	0 -3.90 v	1.99	-1726 v	1.99	0 ma	.18	0 ma	17.41 v	4.1 v	INPUT CURRENT TO HIGH, HEATER VOLTAGE TOO LOW
HEATER SHORTED 5 Ω Δ FROM NOMINAL	1.39	127 ma -61 ma	2.73	1.61 v	2.00	-1726 v	1.97	.006 ma	.20	.007 ma	17.39 v	9.89 v	INPUT CURRENT TOO HIGH
HEATER SHORTED 7 Ω Δ FROM NOMINAL	1.47	159 ma -29 ma	2.99	2.07 v	1.82	-1740 v	1.99	.036 ma	.32	.04 ma	17.17 v	11.36 v	INPUT CURRENT TOO HIGH
HEATER SHORTED 10 Ω Δ FROM NOMINAL	1.66	181 ma -7 ma	3.24	2.24 v	2.19	-1727 v	2.48	.78 ma	2.15	.51 ma	N/A	13.77 v	INPUT CURRENT TOO HIGH
HEATER SHORTED 20 Ω Δ FROM NOMINAL	1.74	219 ma +31 ma	3.95	3.77 v	2.21	-1729 v	3.61	5.3 ma	.85	.195 ma	N/A	17.35 v	INPUT CURRENT TOO HIGH
HELIX/HEATER SHORT (100K Ω) Δ FROM NOMINAL	7.87	1.88 a +1.69 a	3.94	3.0 v	2.48	-1639 v	8.08	4.9 ma	7.99	.23 ma	N/A	N/A	INPUT CURRENT TOO HIGH
HELIX/HEATER SHORT (200K Ω) Δ FROM NOMINAL	7.88	1.02 a +.83 a	3.94	3.0 v	2.37	-1735 v	6.64	5.5 ma	7.95	.175 ma	N/A	N/A	INPUT CURRENT TOO HIGH
60 Ω RESISTANCE IN CATHODE LEAD	2.31	N/A	3.14	3.0 v	.017	-1349 v	2.34	.26 ma	1.00 drpg.	.27 ma	N/A	N/A	CATHODE VOLTAGE TOO HIGH HELIX CURRENT TOO HIGH
15 Ω RESISTANCE IN SERIES WITH HEATER Δ FROM NOMINAL	1.28	100 ma -88 ma	3.93	3.76 P.S. 1.43 TWT	1.70	-1731 v	1.90	0 ma	.19	0 ma	17.32 v	17.00 v	HEATER VOLTAGE TOO HIGH

Table 5. Summary of TWT Failure Modes and Effects Testing. (The tested failure modes did not yield a significantly close failure signature to the observed post-failure orbit data.)

FAILURE MODE	INPUT CURRENT		FILAMENT VOLTAGE		CATHODE VOLTAGE		CATHODE CURRENT		HELIX CURRENT		SWITCHING REG. VOLTAGE	LINEAR REG. VOLTAGE	REMARKS
	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE			
BREADBOARD NOMINAL	1.66	188 ma	3.91	3.90 v	2.23	-1730 v	3.62	5.3 ma	0.82	.186 ma	18.69 v	17.37 v	
CR1 OR CR2 OPEN Δ FROM NOMINAL	1.66 0	185 ma -3 ma	4.93 +1.02	3.64 v -.26 v	2.18	-1728 v	3.63	5.15 ma	.912	.196 ma	18.85 v	17.36 v	INPUT CURRENT & HEATER VOLTAGE TOO HIGH
CR1 OR CR2 SHORT Δ FROM NOMINAL	1.43	131 ma	2.03 -1.88	0 v -3.90 v	1.99	-1726 v	2.00	0 ma	0.18	0 ma	17.38 v	2.0 v	FILAMENT VOLTAGE TOO LOW
CR1 AND CR2 OPEN Δ FROM NOMINAL	.994	N/A	5.79 +2.48	0 v -3.90 v	2.07	-1734 v	1.87	0 ma	.248	0 ma			FILAMENT VOLTAGE TELEMETRY TOO HIGH
3Ω RESISTANCE IN PLACE OF CR2 Δ FROM NOMINAL	1.35 -.31	121 ma -67 ma	3.02 -.89	.38 v -3.52 v	1.85 -.38	-1723 v	1.98	0 ma	.25	0 ma	17.28 v	5.08 v	INPUT CURRENT & FILAMENT VOLTAGE TELEMETRY SLIGHTLY HIGH
24Ω RESISTANCE IN PARALLEL CR2 Δ FROM NOMINAL	1.77 +.11	209 ma +21 ma	4.53 +.62	3.0 v -.9 v	2.18	-1728 v	2.87	1.7 ma	2.81	.68 ma	18.85 v	14.24 v	INPUT CURRENT & FILAMENT VOLTAGE TELEMETRY TOO HIGH
3Ω RESISTANCE IN PARALLEL CR2 Δ FROM NOMINAL	1.35 -.31	121 ma -67 ma	3.00 -.91	.46 v -3.44 v	1.83 -.40	-1723 v	1.97	0 ma	.23	0 ma	17.27 v	5.03 v	INPUT CURRENT & FILAMENT VOLTAGE TELEMETRY SLIGHTLY HIGH
OPEN C8 Δ FROM NOMINAL	1.67 4.01	190 ma +2 ma	4.03 +.12	3.91 v +.01 v	2.22	-1732 v	3.66	5.35 ma	.87	.18 ma	18.66 v	17.36 v	INPUT CURRENT TO FILAMENT VOLTAGE TOO HIGH
SHORT C8	SAME	AS SHORTED	HEATER										

Table 6. Summary of HV Module Failure Modes and Effects Testing. (One tested failure mode, partial short of CR1 or CR2, does provide a reasonable, although not exact, replication of the orbit failure signature.)

3.2.3 Semiconductor Module Failures

The final group of failure simulation tests were performed on the linear regulator and telemetry boards in the semiconductor module. A summary of the results of these tests is given in Table 7. As with the previous two sets of tests, none of the specific failure simulations yielded a characteristic signature identical to the one in orbit. However, it becomes apparent that the orbit failure signature could be very closely reproduced under the condition where the heater voltage decreased to the point where the TWT beam is extinguished. A test of three similar TWTs showed that this occurred when the heater voltage was at 2.6, 2.85, and 2.9 V. The heater voltage in the flight TWTA is indicated to be as low as 2.70 V by telemetry. Thus, this data is consistent with the hypothesis that the beam has been extinguished in the flight TWT by a failure in the linear regulator which has reduced the heater voltage to 2.7 to 3.0 V. This level of heater voltage would exist if the series regulator output voltage had been reduced to about 13 V from its nominal value of 17.5 V.

A specific failure mode which did not appear likely is an open or short of the transistors (A1-Q10 and A1-Q11) used to drive the primary windings of the heater high voltage transformer. The test results showed this type of failure produced grossly different symptoms from the one experienced in orbit.

A number of component failures could reduce the linear regulator output to the signatured values. These can be listed:

- A shift in value of semiconductor module SIT R6 from a nominal 5 Ω to 10 Ω
- A partial short (50 to 75 Ω) of A2-CR20 or A2-CR21
- A reduction in gain in A2-Q2
- Any failure in the sense and control circuitry which controls A2-Q2 and hence regulates the output voltage of the linear regulator.

The most likely parts in the linear regulator are the elements in the pass circuit; i.e., the first three listed above. Hence, these were selected for additional investigation described in subsequent sections of this report.

FAILURE MODE	INPUT CURRENT		FILAMENT VOLTAGE		CATHODE VOLTAGE		CATHODE CURRENT		HELIX CURRENT		SWITCHING REG. VOLTAGE	LINEAR REG. VOLTAGE	
	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE			
BREADBOARD NOMINAL	1.66	188 ma	3.91	3.90 v	2.23	-1730 v	3.62	5.3 ma	0.82	0.186 ma	18.69 v	17.37 v	
BASE/EMITTER SHORT A1-Q10	3.56	N/A	3.76	3.7 v	2.189	-1727 v	3.37	4.1 ma	1.48	0.45 ma	N/A v	N/A	CATHODE & HELIX CURRENT TOO HIGH
COLLECTOR/EMITTER SHORT A1-Q11 Δ FROM NOMINAL	1.40 -.26	149 ma -39 ma	0 -3.91	0 -3.90 v	1.75	-1726 v	1.93	0 ma	.242	0 ma	16.90 v	0.24 v	FILAMENT VOLTAGE TOO LOW
EMITTER OPEN A1-Q11 Δ FROM NOMINAL	1.78 +.12	227 ma +39 ma	7.74 +3.83	3.27 v -.63 v	2.18	-1729 v	3.42	4.1 ma	2.07	0.52 ma	18.92 v	17.33 v	INPUT CURRENT TOO HIGH
SHORT OF A2-R35 (0Ω) Δ FROM NOMINAL	1.25 -.41	91 ma -97 ma	1.21 -2.70	1.02 v -2.88 v	1.81	-1733 v	1.91	0 ma	.18	0 ma	16.8 v	6.48 v	FILAMENT VOLTAGE TOO LOW
200K SHORT OF A2-R35 Δ FROM NOMINAL	1.65 -.01	168 ma -20 ma	3.06 -.85	3.02 v -.88 v	2.21	-1731 v	2.88	2.8 ma -2.5 ma	2.86	0.74 ma +.554 ma	19.01 v	13.91 v	INPUT, CATHODE, AND HELIX CURRENT TOO HIGH
PARTIAL SHORT A2-CR20 (79Ω in 11) Δ FROM NOMINAL	1.61	151 ma -36 ma	2.92	2.90 v	2.19	-1729 v	2.70	1.7 ma -3.6 ma	2.53	.6 ma +.414 ma	18.68 v	13.24 v	INPUT, CATHODE & HELIX CURRENT TOO HIGH
PARTIAL SHORT A2-CR20 (51Ω in 11) Δ FROM NOMINAL	1.27	103 ma -85 ma	1.47	1.29 v -1.61 v	1.73	-1729 v	1.93	0 ma	.241	0 ma	16.82 v	7.45 v	FILAMENT VOLTAGE TOO LOW
PARTIAL SHORT A2-C16 (196Ω in 11) Δ FROM NOMINAL	1.77	212 ma +24 ma	3.05	3.00 v -.90 v	2.18	-1728 v	2.91	2.07 ma -3.43 ma	2.86	.07 ma	18.91 v	13.96 v	INPUT & CATHODE CURRENT TOO HIGH

Table 7. Summary of Semiconductor Failure Modes and Effects Testing. (Failure modes which reduced the linear regulator output to approximately 13 V would cause the TWT beam to be extinguished. This type of failure is consistent with the characteristics of the orbit anomaly.)

FAILURE MODE	INPUT CURRENT		FILAMENT VOLTAGE		CATHODE VOLTAGE		CATHODE CURRENT		HELIX CURRENT		SWITCHING REG. VOLTAGE	LINEAR REG. VOLTAGE	
	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE			
OPEN A3-CR10 △ FROM NOMINAL	1.67	190 ma +2 ma	3.83	3.94 v +.04 v	2.22	-1732 v	3.66	5.4 ma +.1 ma	.855	.18 ma .006ma	18.66 v	17.37 v	ALL CURRENTS & FILAMENT VOLTAGE TOO HIGH
SHORTED A3-CR10 △ FROM NOMINAL	1.40	148 ma 40 ma	.242	0.47 v -3.43 v	1.75	-1728 v	1.93	0 ma	.240	0 ma	16.92 v	4.65 v	INPUT CURRENT TOO HIGH, FILAMENT VOLTAGE TOO LOW
PARTIALLY SHORTED A3-CR10 (28 Ω in 11)	1.81	226 ma	3.00	3.15 v	2.13	-1723 v	3.18	2.75 ma	3.01	.76 ma			ALL CURRENTS & FILAMENT VOLTAGE TOO HIGH
SHORTED A3-C3 △ FROM NOMINAL	1.40	130 ma -58 ma	.032	0.92 v -2.98 v	2.0	-1728 v	2.0	0 ma	.243	0 ma	17.42 v	6.44 v	FILAMENT VOLTAGE LOW, INPUT CURRENT HIGH
PARTIALLY SHORTED A3-C3 (16 Ω in 11) △ FROM NOMINAL	1.77	228 ma +40 ma	3.00	3.71 v -.19 v	2.19	-1728 v	3.63	5.7 ma	.921	.20 ma	18.63 v	16.59 v	ALL CURRENTS & FILAMENT VOLTAGE TOO HIGH
DEGRADED GAIN SCM-Q2 (180 Ω in 11 B-E) △ FROM NOMINAL	1.58	147 ma -41 ma	2.89	2.92 v	2.14	-1724 v	2.60	1.6 ma	2.38	.6 ma	19.16 v	3.00 v	
CHANGE IN VALUE SCM-R6 (10 Ω) △ FROM NOMINAL	1.56	148 ma -40 ma	2.92	2.89 v -1.01 v	2.19	-1728 v	2.59	1.38 ma	2.46	.64 ma	18.78 v	13.63 v	INPUT & CATHODE CURRENT TOO HIGH
CHANGE IN VALUE SCM-R6 (15 Ω) △ FROM NOMINAL	1.26	91 ma -97 ma	1.53	1.36 v -2.54 v	1.76	-1728 v	1.91	0 ma	.254	0 ma	16.71 v	7.69 v	FILAMENT VOLTAGE TOO LOW

Table 7. Summary of Semiconductor Failure Modes and Effects Testing (Continued)

4. PARTS REVIEW

The analysis and testing performed during the investigation identified certain specific parts which could be the source of the F8 orbit anomaly. Each of these was viewed in detail in order to attempt to reach an assessment as to relative likelihood of occurrence and the likelihood that a similar failure or failures could be expected in the LLTWTAs on inventory for F9-F12. The potential failure modes identified for review were the following:

- Partial short of the TWT heater
- Partial short of CR1 or CR2 in high voltage module
- Gain degradation of pass transistor in linear regulator (A2-Q2)
- Partial short of bias diodes in semiconductor module, A2-CR20 and A2-CR21
- Partial short of output filter capacitor, C16
- Partial short of linear regulator filter capacitor, C8.

The coiled heater is made of tungsten wire which is cataphoritically coated with aluminum oxide. The heater is encased in a split cup made of aluminum oxide. One end of the heater is spot welded to the cathode body. The other end of the heater passes through a small diameter hole in the aluminum oxide cup, then through a larger diameter hole in the metallic heat shield, and is spot welded to a tab on a cross-member which connects to the heater ring on the gun body. The critical portions of this assembly are illustrated in Figure 9. From an examination of the geometry, it appears the only likelihood of a short of any significance is where the heater lead passes through the aluminum heat shield. Contact at this point, sufficient to cut through the aluminum oxide coating, could result in a high impedance short. However, the possibility of this type of short is very remote, particularly since the clearance hole in the metallic heat shield is specifically made larger than the matching hole in the aluminum oxide cup. This situation, supported by the lack of previous failures of this heater assembly, was judged to be a very unlikely source of the orbit anomaly.

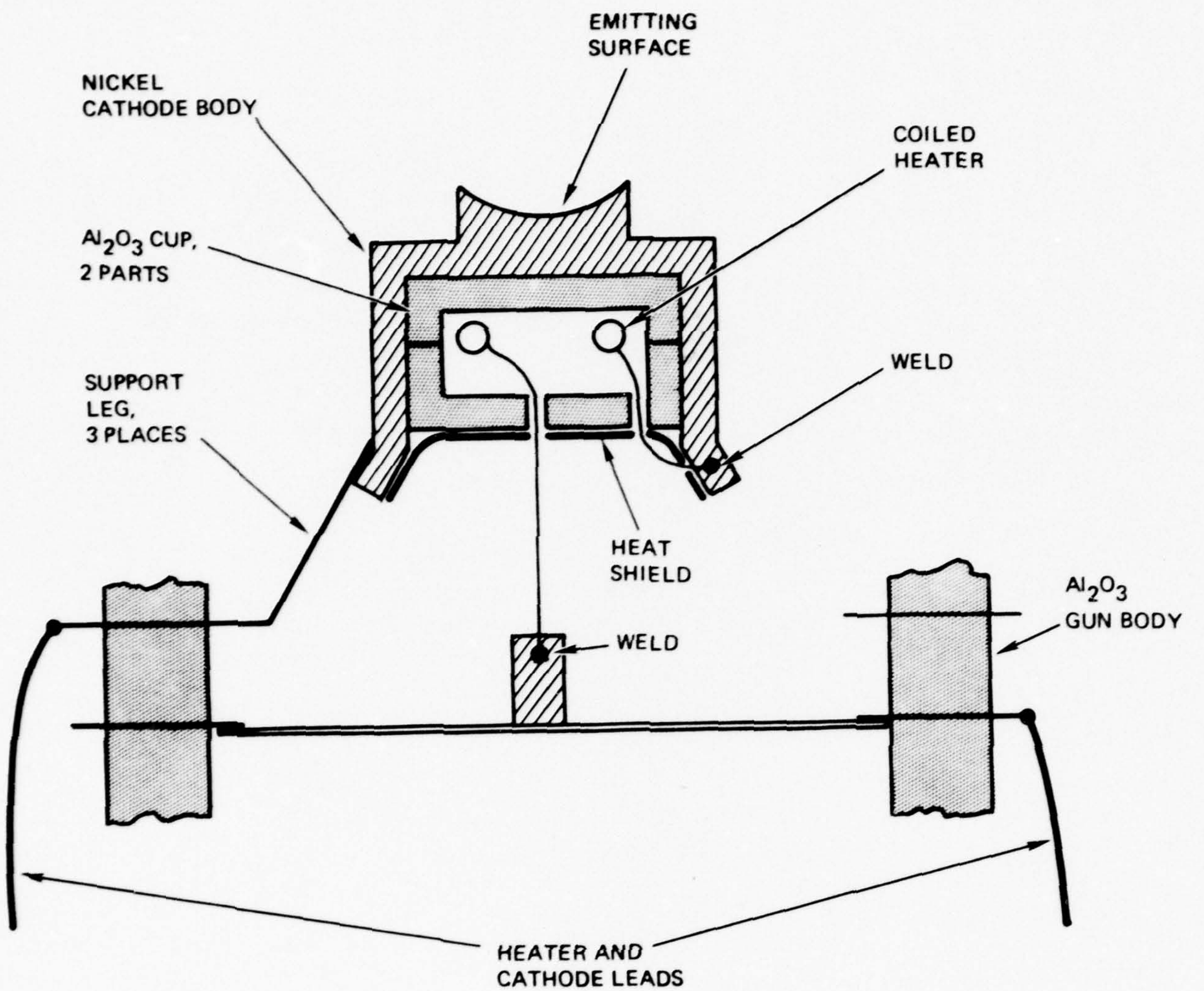


Figure 9. Cross-Section of Heater-Cathode Assembly. (The critical part of the assembly is the point where the heater lead passes through the aluminum heat shield.)

The rectifier diodes (CR1 and CR2) are IN 5417s built to JANTX requirements and upgraded to JANTXV parts at the vendor's. No irregularities existed in the component test data. These diodes are metallurgically bonded, and no potential defects were observed in the DPA sample.

The first components selected for analysis in the semiconductor modules were the pass transistors in the linear regulator (A2-Q2). This device, a 2N2907A, is bought as a JANTXV part. The component test data and DPA on the lot of these devices used in this build of LLTWTAs were excellent, with no irregularities. In addition, the vendor reports no known failure history of this type of part.

The bias diodes (A2-CR20 and A2-CR21) in the semiconductor module are IN4148s bought as JANTX parts and upgraded to JANTXV standards by the vendor. These diodes are a compression contact rather than metallurgically bonded design and are subject to some misalignment. However, it was concluded that the upgrading inspection and X-ray process has removed any badly aligned diodes and tilted dice so that shorting or partial shorting of these parts as a failure mode is remote.

Two capacitors were also investigated. One (C8) is the output filter capacitor on the heater voltage source to the TWT, and the other (A2-C16) the output filter capacitor on the linear regulator. A partial short of either one, if stabilized at the proper equivalent resistance, could cause the orbit anomaly. Both of these are tantalum capacitors, one a solid tantalum (C16) and the other a sintered mode (wet slug) polarized tantalum capacitor. The screening and DPA data for C16 showed no anomalous or non-typical indications. Hence, a failure of this part would appear very unlikely.

The second capacitor type (C8) had one device of the 12 used for lot qualification show a higher than specified (1.8 ma versus 1 ma) leakage current after an 8-hour vibration exposure. However, during the subsequent life test (2,000 hours), the leakage current values were within specified limits. Since the leakage current remained low during the life test, it was concluded that vibration is not a cause for device failure or reason for concern.

The manufacturing data package for the failed LLTWTA was reviewed in detail to determine whether some irregularity had occurred during the buildup and

ground testing which could possibly explain the orbit failure. Although the data packages documented various squawks and associated rework activities, the corrective actions taken at the time by the TWTA manufacturer seemed appropriate. There was no reason to feel that this TWTA had not been built and tested properly.

5. CONCLUSIONS

Because it was possible to contrive several different failure modes which yielded signatures similar to the limited satellite telemetry data, it was not possible to pinpoint one specific cause for the orbit anomaly. However, all evidence at hand indicated the failure had occurred somewhere in the TWT heater or the heater power supply. This includes either the linear regulator, the DC to DC converter, or the TWT heater. The piece part failures which most closely fit the flight telemetry signatures are: a partial short of bias diode CR20 or CR21, a change in value of R6, or a gain reduction in Q2 or any parasitic path which effectively results in the same degradation of the linear regulator circuit in the semiconductor module. Each individual failure mode which could have caused this anomaly was judged to be extremely remote. Also, no evidence was found which would indicate there was any sort of defect in the F8 LLTWTA or any of the units in inventory for F9 through F12. The conclusion is that this failure should be considered isolated in nature, not subject to repeat. No corrective action for the LLTWTAs in inventory for F9 through F12 is recommended.

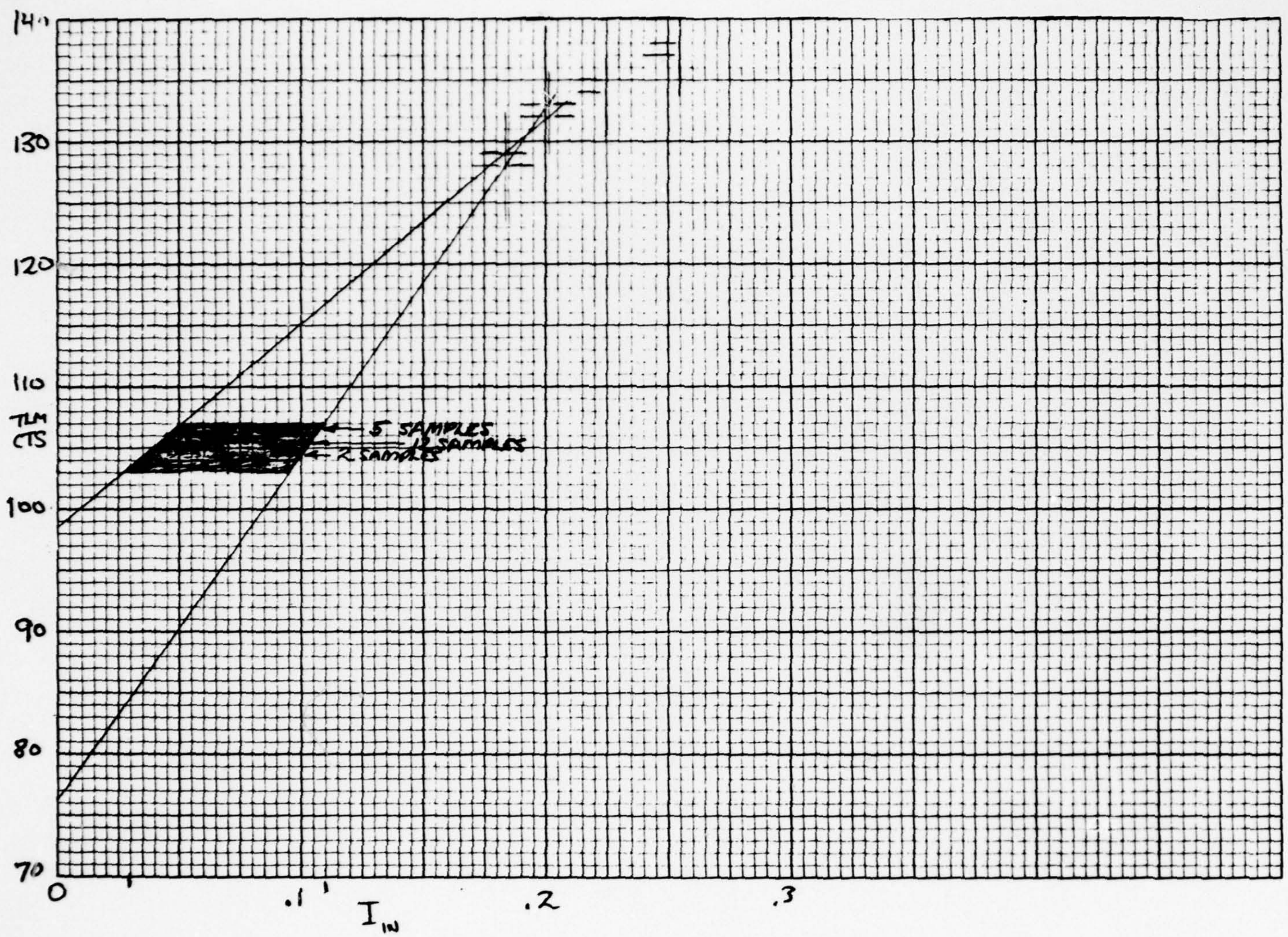
APPENDIX A

LLTWTA TELEMETRY CALIBRATION DATA

9438 SCF Calibration Curves - No. 2 NCLLTWTA

SUBC	WORD	SLOPE CNTS	SLOPE Value	Parameter	REMARKS
3	30	0 132 255	-.447 .213 1.511	NCLL2I (Input Current) AMPS	2 segments 1ST = 5.10ma/CNT 2nd = 10.55ma/CNT ON-ORBIT and I&T Cals are the same
3	46	139 255	2.505 10.54	NCLLKI (Cathode Current) milliamps	1 segment slope = .06923ma/CNT This segment is the same as I&T. BELOW 139 CNTS the slope does not follow the I&T cal curve
3	62	0 255	1355 2161	NCLLHV (Helix Voltage) volts	1 segment slope = 3.16v/CNT Same as I&T Cal curve
4	7	0 255	-.077 1.354	NCLLHI (Helix Current) milli amps	1 segment slope = 5.58μa/CNT Same as I&T Cal curve
4	10	160 255	3.301 4.509	NCLLFV (Filament voltage) volts	1 segment Slope = .01285v/CNT This segment is the same as I&T. BELOW 160CNT. the slope does not follow the I&T cal curve

Uncertainty Analysis - LLTWTA Input Current TLM Calibration

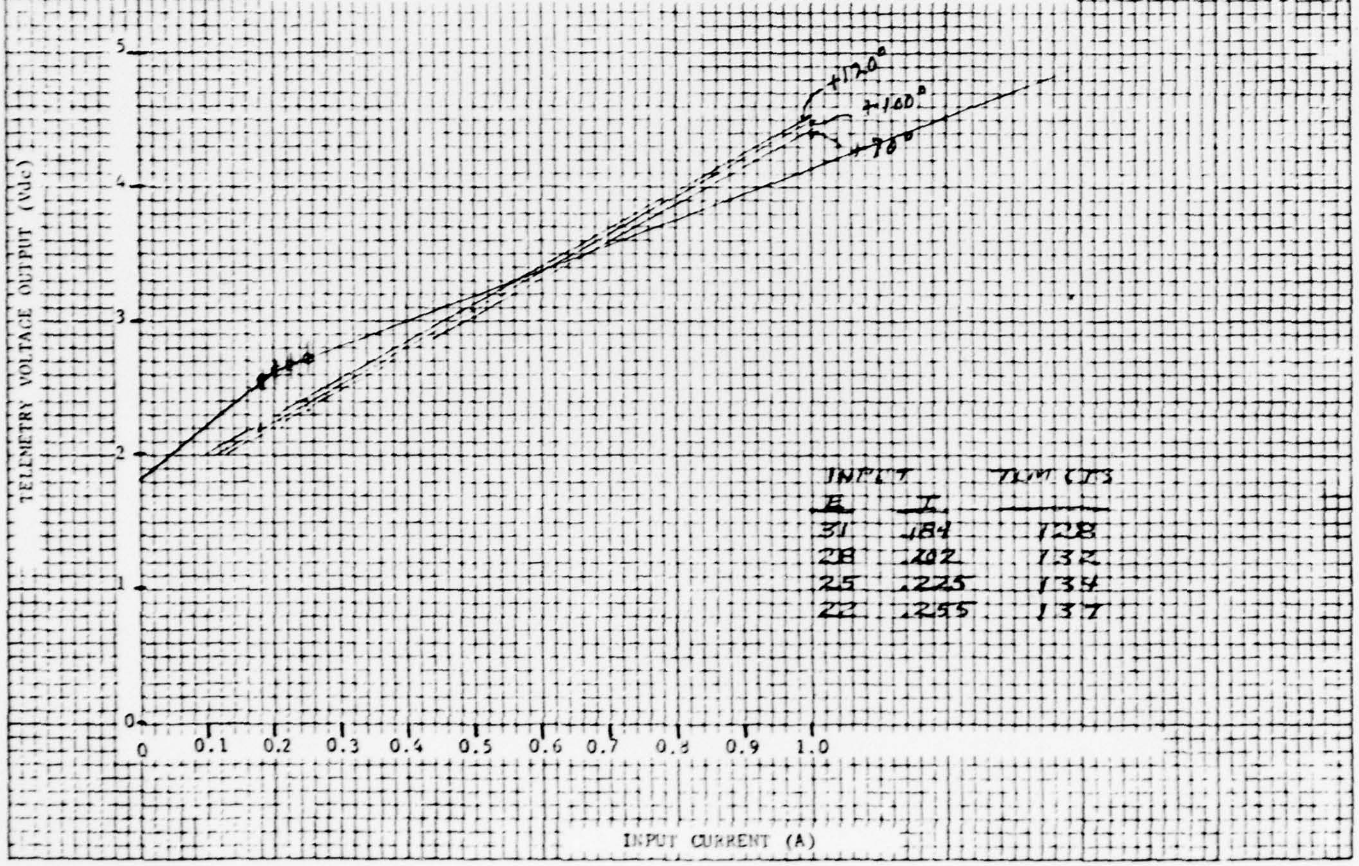


HUGHES ELECTRON DYNAMICS DIVISION

TEST DATA SHEET

DATA SHEET NO. DSB200302-410
REV. A
SERIAL NO. 016

INPUT CURRENT TELEMETRY VS. TEMPERATURE CALIBRATION CURVE



CALFILE ID FLT8 CREATE DATE 11/ 22/ 76

PAGE NCLL UNIT AMPS

F1 I 3 30 NC B LL INPUT I 0377

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0010	-0.397	-0.392	-0.387	-0.382	-0.377	-0.372	-0.367	-0.362	-0.357	-0.352
0020	-0.347	-0.342	-0.337	-0.332	-0.327	-0.322	-0.317	-0.312	-0.307	-0.302
0030	-0.297	-0.292	-0.287	-0.282	-0.277	-0.272	-0.267	-0.262	-0.257	-0.252
0040	-0.247	-0.242	-0.237	-0.232	-0.227	-0.222	-0.217	-0.212	-0.207	-0.202
0050	-0.197	-0.192	-0.187	-0.182	-0.177	-0.172	-0.167	-0.162	-0.157	-0.152
0060	-0.147	-0.142	-0.137	-0.132	-0.127	-0.122	-0.117	-0.112	-0.107	-0.102
0070	-0.097	-0.092	-0.087	-0.082	-0.077	-0.072	-0.067	-0.062	-0.057	-0.052
0080	-0.047	-0.042	-0.037	-0.032	-0.027	-0.022	-0.017	-0.012	-0.007	-0.002
0090	0.002	0.007	0.012	0.017	0.022	0.027	0.032	0.037	0.042	0.047
0100	0.052	0.057	0.062	0.067	0.072	0.077	0.082	0.087	0.092	0.097
0110	0.102	0.107	0.112	0.117	0.122	0.127	0.132	0.138	0.143	0.148
0120	0.153	0.158	0.163	0.168	0.173	0.178	0.183	0.188	0.193	0.198
0130	0.203	0.208	0.213	0.215	0.226	0.237	0.247	0.258	0.269	0.279
0140	0.290	0.300	0.311	0.322	0.332	0.343	0.354	0.364	0.375	0.385
0150	0.396	0.407	0.417	0.428	0.438	0.449	0.460	0.470	0.481	0.492
0160	0.502	0.513	0.523	0.534	0.545	0.555	0.566	0.577	0.587	0.598
0170	0.608	0.619	0.630	0.640	0.651	0.662	0.672	0.683	0.693	0.704
0180	0.715	0.725	0.736	0.746	0.757	0.768	0.778	0.789	0.800	0.810
0190	0.821	0.831	0.842	0.853	0.863	0.874	0.885	0.895	0.906	0.916
0200	0.927	0.938	0.948	0.959	0.969	0.980	0.991	1.001	1.012	1.023
0210	1.033	1.044	1.054	1.065	1.076	1.086	1.097	1.108	1.118	1.129
0220	1.139	1.150	1.161	1.171	1.182	1.193	1.203	1.214	1.224	1.235
0230	1.246	1.256	1.267	1.277	1.288	1.299	1.309	1.320	1.331	1.341
0240	1.352	1.362	1.373	1.384	1.394	1.405	1.416	1.426	1.437	1.447
0250	1.458	1.469	1.479	1.490	1.500	1.511				

CALFILE ID FLTR CREATE DATE 11/ 22/ 76

PAGE NCLL UNIT VOLTS

F1 I 3 62 NC B LL HELIX V 0377

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0030	1450.	1453.	1456.	1460.	1463.	1466.	1469.	1472.	1475.	1478.
0040	1482.	1485.	1488.	1491.	1494.	1497.	1501.	1504.	1507.	1510.
0050	1513.	1516.	1520.	1523.	1526.	1529.	1532.	1535.	1538.	1542.
0060	1545.	1548.	1551.	1554.	1557.	1561.	1564.	1567.	1570.	1573.
0070	1576.	1580.	1583.	1586.	1589.	1592.	1595.	1598.	1602.	1605.
0080	1608.	1611.	1614.	1617.	1621.	1624.	1627.	1630.	1633.	1636.
0090	1640.	1643.	1646.	1649.	1652.	1655.	1658.	1662.	1665.	1668.
0100	1671.	1674.	1677.	1681.	1684.	1687.	1690.	1693.	1696.	1700.
0110	1703.	1706.	1709.	1712.	1715.	1718.	1722.	1725.	1728.	1731.
0120	1734.	1737.	1741.	1744.	1747.	1750.	1753.	1756.	1760.	1763.
0130	1766.	1769.	1772.	1775.	1778.	1782.	1785.	1788.	1791.	1794.
0140	1797.	1801.	1804.	1807.	1810.	1813.	1816.	1820.	1823.	1826.
0150	1829.	1832.	1835.	1838.	1842.	1845.	1848.	1851.	1854.	1857.
0160	1861.	1864.	1867.	1870.	1873.	1876.	1880.	1883.	1886.	1889.
0170	1892.	1895.	1898.	1902.	1905.	1908.	1911.	1914.	1917.	1921.
0180	1924.	1927.	1930.	1933.	1936.	1940.	1943.	1946.	1949.	1952.
0190	1955.	1958.	1962.	1965.	1968.	1971.	1974.	1977.	1981.	1984.
0200	1987.	1990.	1993.	1996.	2000.	2003.	2006.	2009.	2012.	2015.
0210	2018.	2022.	2025.	2028.	2031.	2034.	2037.	2041.	2044.	2047.
0220	2050.	2053.	2056.	2060.	2063.	2066.	2069.	2072.	2075.	2078.
0230	2082.	2085.	2088.	2091.	2094.	2097.	2101.	2104.	2107.	2110.
0240	2113.	2116.	2120.	2123.	2126.	2129.	2132.	2135.	2138.	2142.
0250	2145.	2148.	2151.	2154.	2157.	2161.				

HUGHES ELECTRON DYNAMICS DIVISION

HUGHES AIRCRAFT COMPANY

TEST DATA SHEET

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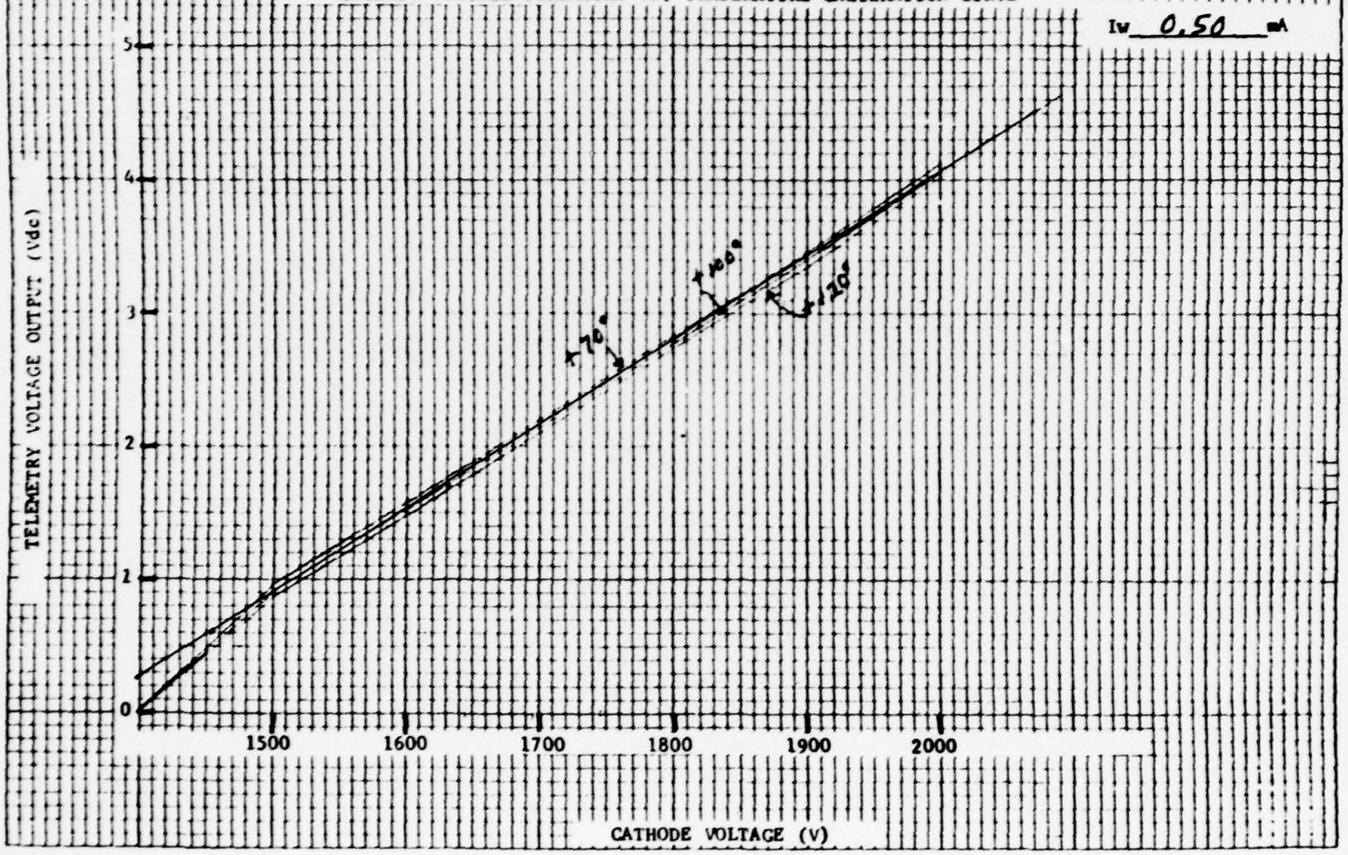
CATHODE VOLTAGE TELEMETRY VS. TEMPERATURE CALIBRATION CURVE

Iv 0.50 mA



CALFILE ID FLTR CREATE DATE 11/ 22/ 76

PAGE NCLL UNIT MA

F1 I 4 7 NC B LL HFLIX I 0377

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0010	-0.021	-0.015	-0.010	-0.004	0.001	0.006	0.012	0.017	0.023	0.029
0020	0.034	0.040	0.046	0.051	0.057	0.062	0.068	0.074	0.079	0.085
0030	0.090	0.096	0.102	0.107	0.113	0.119	0.124	0.130	0.135	0.141
0040	0.147	0.152	0.158	0.163	0.169	0.175	0.180	0.186	0.192	0.197
0050	0.203	0.208	0.214	0.220	0.225	0.231	0.236	0.242	0.248	0.253
0060	0.259	0.264	0.270	0.276	0.281	0.287	0.293	0.298	0.304	0.309
0070	0.315	0.321	0.326	0.332	0.337	0.343	0.349	0.354	0.360	0.366
0080	0.371	0.377	0.382	0.388	0.394	0.399	0.405	0.410	0.416	0.422
0090	0.427	0.433	0.439	0.444	0.450	0.455	0.461	0.467	0.472	0.478
0100	0.483	0.489	0.495	0.500	0.506	0.512	0.517	0.523	0.528	0.534
0110	0.540	0.545	0.551	0.556	0.562	0.568	0.573	0.579	0.585	0.590
0120	0.596	0.601	0.607	0.613	0.618	0.624	0.629	0.635	0.641	0.646
0130	0.652	0.658	0.663	0.669	0.674	0.680	0.686	0.691	0.697	0.702
0140	0.708	0.714	0.719	0.725	0.731	0.736	0.742	0.747	0.753	0.759
0150	0.764	0.770	0.775	0.781	0.787	0.792	0.798	0.804	0.809	0.815
0160	0.820	0.826	0.832	0.837	0.843	0.848	0.854	0.860	0.865	0.871
0170	0.877	0.882	0.888	0.893	0.899	0.905	0.910	0.916	0.921	0.927
0180	0.933	0.938	0.944	0.950	0.955	0.961	0.966	0.972	0.978	0.983
0190	0.989	0.994	1.000	1.006	1.011	1.017	1.023	1.028	1.034	1.039
0200	1.045	1.051	1.056	1.062	1.067	1.073	1.079	1.084	1.090	1.096
0210	1.101	1.107	1.112	1.118	1.124	1.129	1.135	1.140	1.146	1.152
0220	1.157	1.163	1.169	1.174	1.180	1.185	1.191	1.197	1.202	1.208
0230	1.213	1.219	1.225	1.230	1.236	1.242	1.247	1.253	1.258	1.264
0240	1.270	1.275	1.281	1.286	1.292	1.298	1.303	1.309	1.315	1.320
0250	1.326	1.331	1.337	1.343	1.348	1.354				

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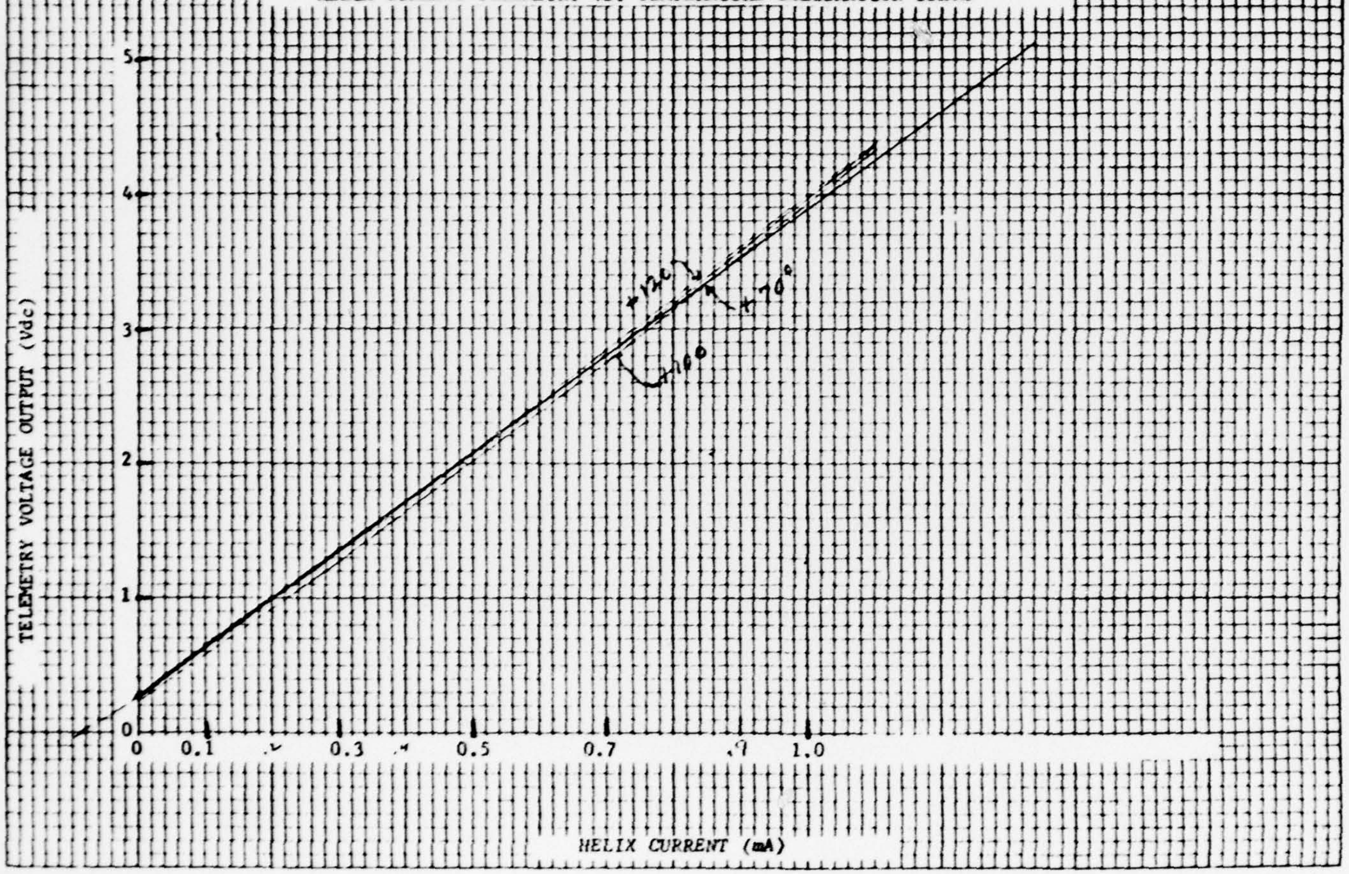
HELIX CURRENT TELEMETRY VS. TEMPERATURE CALIBRATION CURVE



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PAGE NCLL UNIT MA

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0010	-2.833	-2.799	-2.766	-2.733	-2.699	-2.666	-2.633	-2.600	-2.566	-2.533
0020	-2.500	-2.466	-2.433	-2.400	-2.366	-2.333	-2.300	-2.266	-2.233	-2.200
0030	-2.166	-2.133	-2.100	-2.066	-2.033	-2.000	-1.966	-1.933	-1.900	-1.866
0040	-1.833	-1.800	-1.766	-1.733	-1.700	-1.666	-1.633	-1.600	-1.566	-1.533
0050	-1.500	-1.466	-1.433	-1.400	-1.366	-1.333	-1.300	-1.266	-1.233	-1.200
0060	-1.167	-1.133	-1.100	-1.067	-1.033	-1.000	-0.967	-0.933	-0.900	-0.867
0070	-0.833	-0.800	-0.767	-0.733	-0.700	-0.667	-0.633	-0.600	-0.567	-0.533
0080	-0.500	-0.467	-0.433	-0.400	-0.367	-0.333	-0.300	-0.267	-0.233	-0.200
0090	-0.167	-0.133	-0.100	-0.067	-0.033	-0.000	0.032	0.066	0.099	0.132
0100	0.165	0.199	0.232	0.265	0.299	0.332	0.365	0.399	0.432	0.465
0110	0.499	0.532	0.565	0.599	0.632	0.665	0.699	0.732	0.765	0.799
0120	0.832	0.865	0.899	0.932	0.965	0.999	1.111	1.219	1.326	1.433
0130	1.540	1.647	1.754	1.862	1.969	2.076	2.183	2.290	2.398	2.505
0140	2.575	2.645	2.714	2.783	2.853	2.922	2.991	3.060	3.130	3.199
0150	3.268	3.337	3.407	3.476	3.545	3.615	3.684	3.753	3.822	3.892
0160	3.961	4.030	4.100	4.169	4.238	4.307	4.377	4.446	4.515	4.584
0170	4.654	4.723	4.792	4.862	4.931	5.000	5.069	5.139	5.208	5.277
0180	5.346	5.416	5.485	5.554	5.624	5.693	5.762	5.831	5.901	5.970
0190	6.039	6.108	6.178	6.247	6.316	6.386	6.455	6.524	6.593	6.663
0200	6.732	6.801	6.871	6.940	7.009	7.078	7.148	7.217	7.286	7.355
0210	7.425	7.494	7.563	7.633	7.702	7.771	7.840	7.910	7.979	8.048
0220	8.117	8.187	8.256	8.325	8.395	8.464	8.533	8.602	8.672	8.741
0230	8.810	8.879	8.949	9.018	9.087	9.157	9.226	9.295	9.364	9.434
0240	9.503	9.572	9.641	9.711	9.780	9.849	9.919	9.988	10.05	10.12
0250	10.19	10.26	10.33	10.40	10.47	10.54				

HUGHES AIRCRAFT COMPANY

HUGHES ELECTRON DYNAMICS DIVISION

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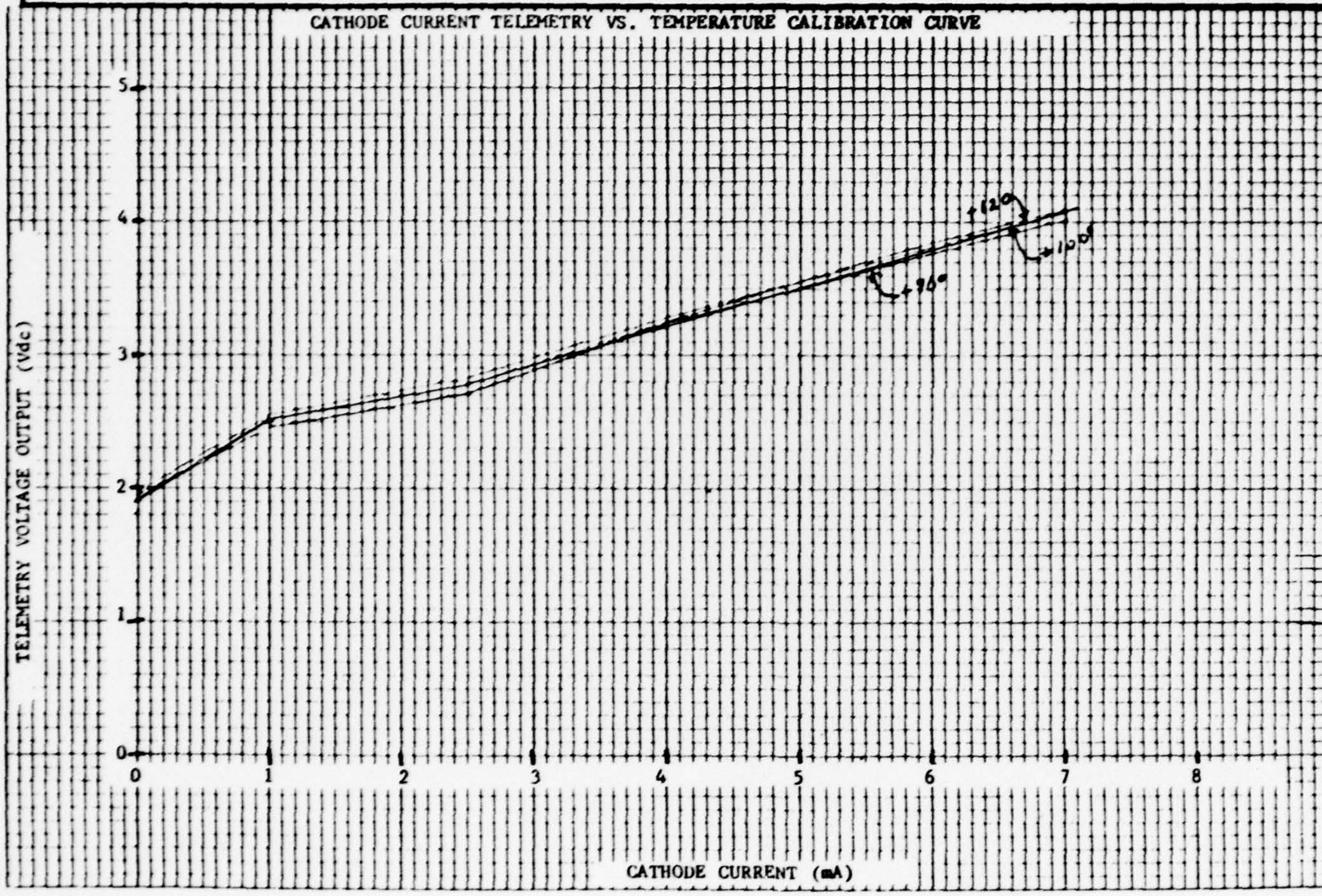
CATHODE CURRENT TELEMETRY VS. TEMPERATURE CALIBRATION CURVE



CALFILE ID FLT8 CREATE DATE 11/ 22/ 76

PAGE NCLL UNIT VOLTS

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0010	0.215	0.236	0.258	0.279	0.301	0.322	0.344	0.365	0.387	0.408
0020	0.430	0.451	0.473	0.494	0.516	0.537	0.559	0.580	0.602	0.623
0030	0.645	0.666	0.687	0.709	0.730	0.752	0.773	0.795	0.816	0.838
0040	0.859	0.881	0.902	0.924	0.945	0.967	0.988	1.010	1.031	1.053
0050	1.074	1.096	1.117	1.139	1.160	1.182	1.203	1.225	1.246	1.268
0060	1.289	1.311	1.332	1.354	1.375	1.396	1.418	1.439	1.461	1.482
0070	1.504	1.525	1.547	1.568	1.590	1.611	1.633	1.654	1.676	1.697
0080	1.719	1.740	1.762	1.783	1.805	1.826	1.848	1.869	1.891	1.912
0090	1.934	1.955	1.977	1.998	2.020	2.041	2.062	2.084	2.105	2.127
0100	2.148	2.170	2.191	2.213	2.234	2.256	2.277	2.299	2.320	2.342
0110	2.363	2.385	2.406	2.428	2.449	2.471	2.492	2.514	2.535	2.557
0120	2.578	2.600	2.621	2.643	2.664	2.686	2.707	2.729	2.750	2.771
0130	2.793	2.814	2.836	2.857	2.879	2.900	2.922	2.943	2.965	2.986
0140	3.008	3.029	3.051	3.072	3.094	3.115	3.137	3.158	3.180	3.201
0150	3.223	3.244	3.266	3.287	3.309	3.330	3.352	3.373	3.395	3.416
0160	3.437	3.459	3.480	3.502	3.517	3.533	3.548	3.563	3.578	3.593
0170	3.608	3.624	3.639	3.654	3.669	3.684	3.699	3.715	3.730	3.745
0180	3.760	3.775	3.790	3.806	3.821	3.836	3.851	3.866	3.881	3.897
0190	3.912	3.927	3.942	3.957	3.972	3.988	4.003	4.027	4.037	4.046
0200	4.056	4.066	4.075	4.085	4.095	4.104	4.114	4.124	4.134	4.143
0210	4.153	4.163	4.172	4.182	4.192	4.202	4.211	4.221	4.231	4.240
0220	4.250	4.260	4.269	4.279	4.289	4.299	4.308	4.318	4.328	4.337
0230	4.347	4.357	4.366	4.376	4.386	4.396	4.405	4.415	4.425	4.434
0240	4.444	4.454	4.464	4.473	4.483	4.493	4.502	4.512	4.522	4.531
0250	4.541	4.551	4.561	4.570	4.580	4.590				

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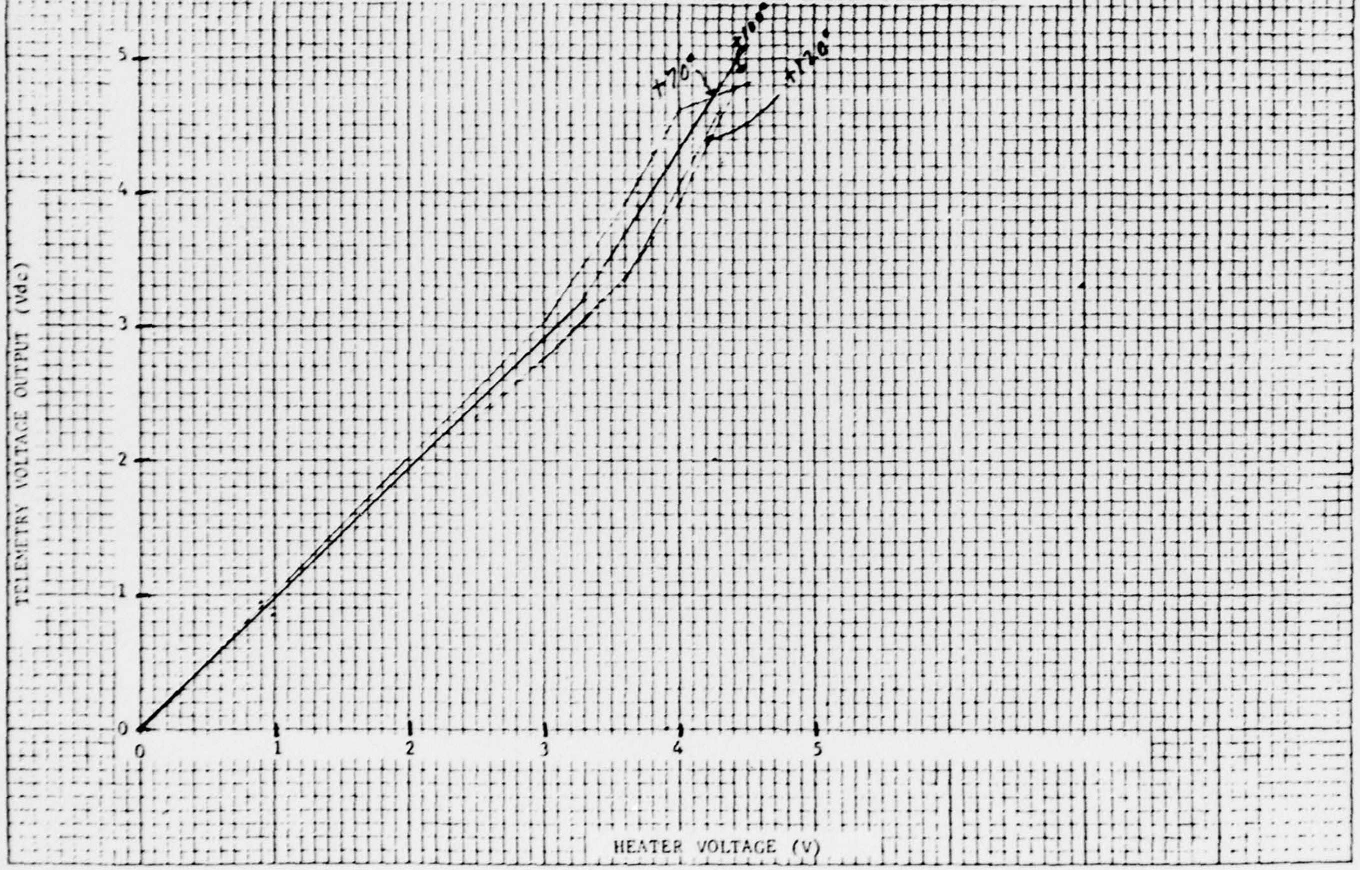
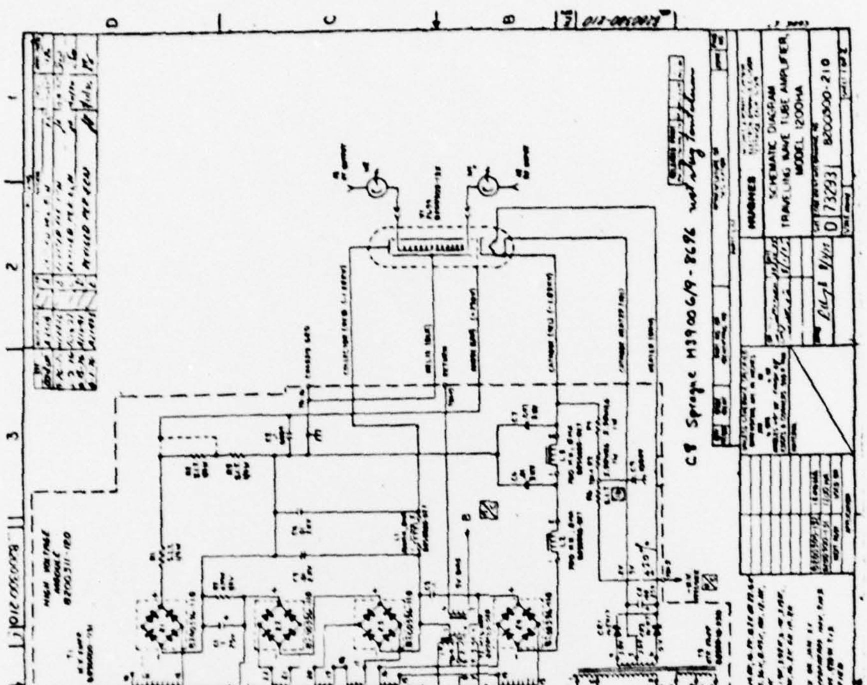
HEATER VOLTAGE TELEMETRY VS. TEMPERATURE CALIBRATION CURVE

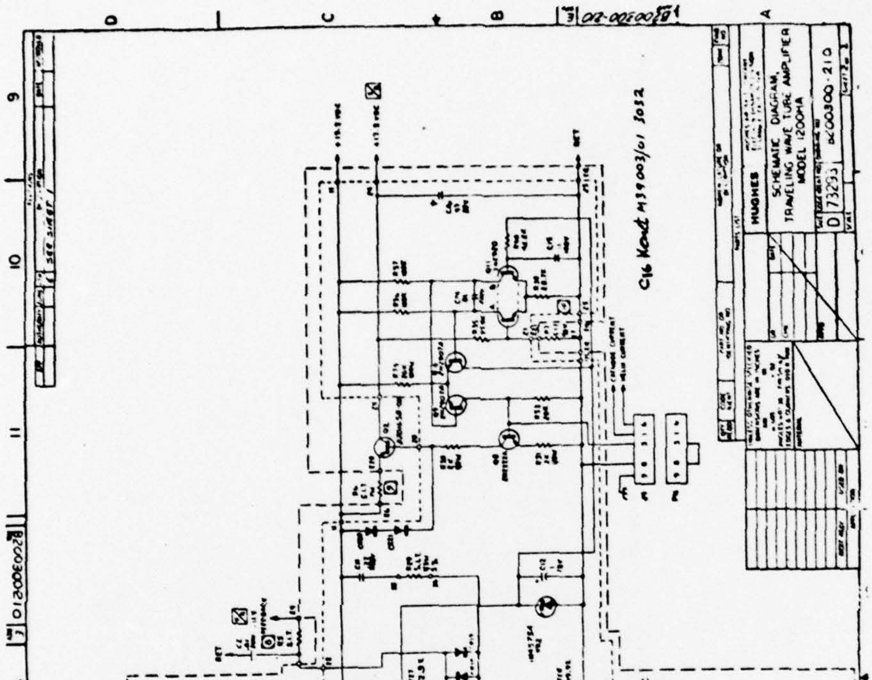


APPENDIX B

LLTWTA SCHEMATIC



HUGHES
SCHEMATIC DIAGRAM
TRAVELING WAVE TUBE AMPLIFIER
MODEL 1200HA
D 73293 B200300-210
C8 Sprague M39006/9-8696


HUGHES
SCHEMATIC DIAGRAM
TRAVELING WAVE TUBE AMPLIFIER